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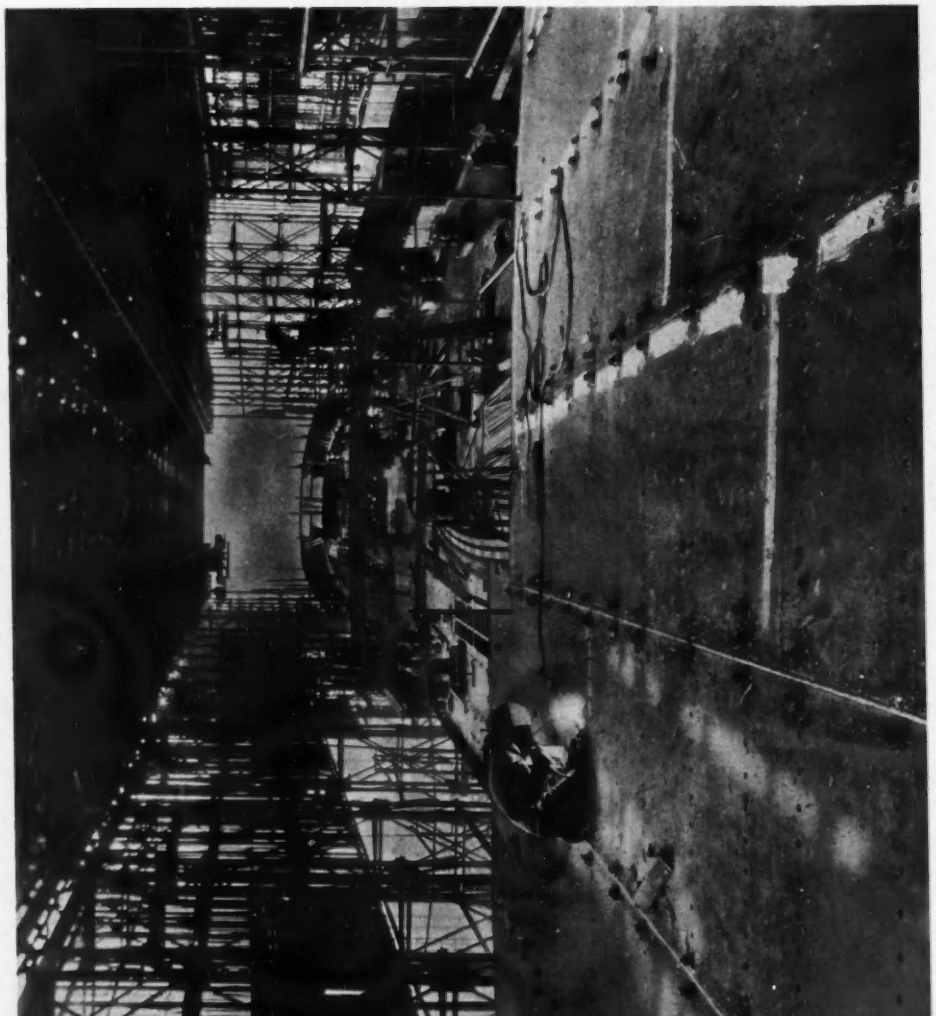


TANKER BUILDING IN A BRITISH SHIPYARD.
Attention is directed to the continuous seams in the welded deck plating, to which reference is made in the following article.

Arc Welding and War Production.

By E. C. DAVIES, A.M.I.E.E.,

Design Department, Witton Engineering Works.

SUMMARY.

IT is generally recognised that electric welding has become one of the most important links in the chain of engineering production on which our war effort depends. The purpose of this article is primarily to emphasise the necessity of examining existing methods of manufacture with the object of introducing fabrication by arc welding as a means of replacing riveting, iron and steel casting, forging, etc., in order to speed up production and to conserve material and labour.

Secondly, it is suggested that by modernising welding methods and taking full advantage of the latest available information regarding high speed welding technique, the time required for welding operations at present undertaken could in many instances be reduced materially. An attempt is made to indicate the main applications for high speed welding and some of the advantages to be derived from their adoption.

Finally, some notes on the selection of welding plant are appended with a review of the relative merits of D.C. and A.C. welding; also some remarks are given concerning the applicability of single- and multi-operator types of equipment.

ARC WELDING UNDER PEACE AND WAR CONDITIONS.

The period 1918-1939 witnessed the emergence of fabrication by arc welding from what was virtually an experimental stage to the position of being recognised as a normal and efficient process, possessing many advantages over previously accepted methods of manufacture. The extent to which it was adopted varied from industry to industry and was controlled largely by specific economic or commercial considerations.

Certain manufacturers, for instance, possessed well equipped foundries, and in consequence were committed to the maximum use of cast components. In the shipbuilding industry, the application of welding was, at least partly, limited by the fact that the layout of the yards, the type of plant installed, and the availability of labour, was based on riveted construction, and a large scale change-over to welding would have involved considerable capital expenditure and labour difficulties.

On the other hand, arc welding was increasingly applied by numerous other manufacturers in the engineering industry who were operating in more favourable circumstances. In these instances the marked advantages offered by the adoption of arc welded fabrication as an alternative to previous manufacturing methods were recognised as most valuable contributions towards the improvement of the product and to production efficiency.

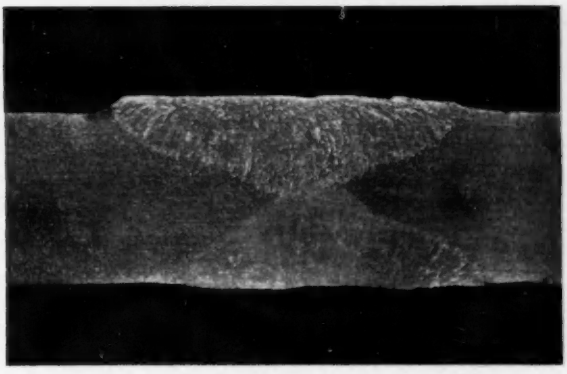


Fig. 1.—Macrograph of butt weld in $\frac{7}{8}$in. mild steel plates.

Generally speaking, therefore, during peace time, arc welding was applied to those products which were either improved and made more saleable in consequence, or were produced at a lower cost by this method. Casting, riveting and forging processes were retained for those products which, for mainly economic reasons, were considered to be unsuitable for fabrication by welding.

The advent of the war, however, created a new set of conditions. The call for maximum speed of production, the necessity for conserving material, and the need for alternative manufacturing facilities to overcome "bottle necks" in certain industries, have shifted the emphasis from purely commercial considerations to those of expediency. In consequence, it is found, for instance, that owing to difficulties in obtaining steel castings due to the commitments of the foundries, components previously considered economically unsuitable for welding are now being fabricated by this method. Further, the need for greater strength has led to the substitution of welded steel for cast iron on equipment installed on board ship.

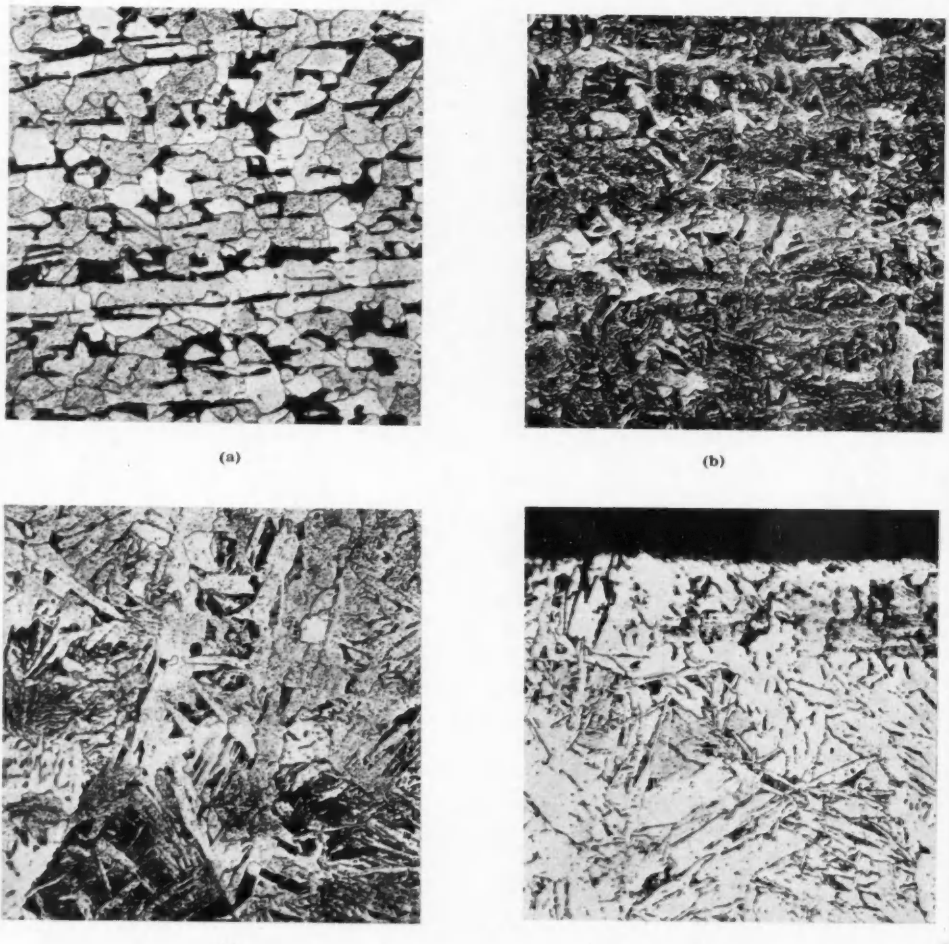


Fig. 2.—Photomicrographs of butt weld as illustrated in fig. 1. (a) Parent plate. (b) Parent plate in thermally disturbed area. (c) Junction of parent plate and weld metal. (d) Outer layer of weld metal. (Magnification × 100).

In the shipbuilding industry there is the tendency to substitute welded structures for members formerly riveted or forged, in order to save steel and to accelerate building.

The use of arc welding is also responsible for the more rapid repair of war material damaged in action, this aspect often having a considerable bearing on the initial design, which in certain cases has been modified to include all-welded construction.

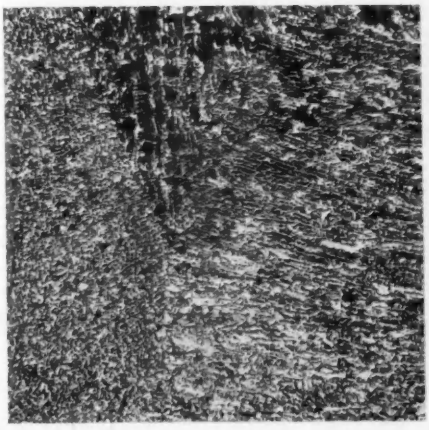


Fig. 3.—Photomicrograph of the junction between first and second deposits and the parent plate. (Magnification × 25).

Many other examples of the wartime application of welding could be quoted to illustrate what has been done already in this direction, but there is no doubt that much more could be achieved with advantage. Reluctance to change over from previously standardised methods to fabrication by welding arises from a variety of reasons, one of the most serious being extreme conservatism or prejudice on the part of certain manufacturers, often traceable to lack of accurate information regarding the possibilities offered by modern welding technique.

Some sympathy is felt for engineers accustomed for a lifetime, perhaps, to certain conventional methods of manufacture and who are suddenly confronted with the problem of adopting unfamiliar and often revolutionary ideas. However, the country's interests demand that every effort should be made to ensure that welding methods are applied in every instance in which an appreciable saving in time and material can be demonstrated. In order to achieve this the technical staffs of the concerns in question should be encouraged to avail themselves of expert advice from welding specialists.

The need for specialised direction in matters of design cannot be too strongly emphasised, since it is usually found that the most efficient welded design differs considerably from its cast or riveted equivalent. The designer is guided not only by the availability of standard rolled plates and sections, but also by the desirability of carrying out as much welding as possible in the downhand position, which, as will be discussed later, enables the work to be performed at the maximum speed.

It is only after comparing a welded design, produced under the guidance of an expert, with that of a non-welded prototype, that it is possible to assess correctly the relative merits of the two. National emergency standards should of course be used for the comparison.

Shortage of skilled labour is undoubtedly one of the major difficulties to be overcome when considering any large-scale changeover to welding, but experience has shown that once a nucleus has been established, a steady supply of welders can be ensured by the institution of training departments within each organization, fed by youths or girls. This system has the advantage of providing a more specialised type of instruction than could be expected from outside training centres and has been proved most valuable as a means of augmenting welding labour obtainable from other sources. In order to conserve the use of skilled welding labour, however, each operation should be carefully examined with the object of securing the maximum saving in time resulting from the adoption of modern welding methods.

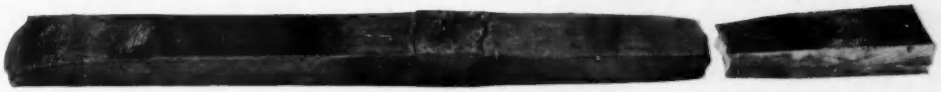


Fig. 4.—High speed welded test piece in ⅜in. mild steel plate after being subjected to tensile test in accordance with British Standard Specification No. 709/1940. Breaking stress 29.1 tons per sq. in.

HIGH SPEED WELDING.

High speed welding is essentially a process which enables a given connection to be completed in the minimum number of runs. This is achieved by the use of special electrodes, usually heavier in gauge than those employed in multiple-run welding, and coated with material designed to allow the rods to operate at a high current density whilst maintaining the quality of the metal deposited. As a result of this increase in arc energy, metal is deposited at a greater rate and with greater penetration than is possible otherwise, and the desired amount of material is thus deposited in the minimum number of layers.

The coating material of these high speed electrodes usually consists of a large percentage of cellulose matter which evolves carbon monoxide and hydrogen during pyrolysis. The de-oxidising effect of these gases is mainly responsible for the protection of the molten metal against atmospheric contamination during transfer from electrode to work, but a small amount of slag is also produced which blankets the deposited metal during the cooling period.

Specific Advantages.

Since high speed welding involves the control of fairly large pools of molten metal, the characteristic of providing complete protection with a minimum amount of slag is one of the reasons for the freedom from trapped slag pockets obtainable from metal deposited from this class of electrode. In addition to the smaller amount of slag produced, the fact that most operations can be completed with a single layer of deposit eliminates the danger of slag inclusions capable of seriously weakening the connection, which in multiple-welding are often traceable to incomplete removal of slag from one run before the covering layer is deposited. The elimination of the time taken for this cleaning is also an important contribution towards maximum speed of production.

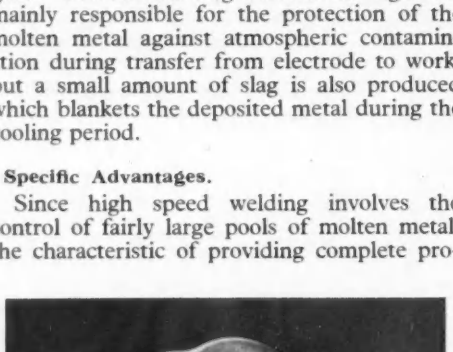


Fig. 5.—Bend test round a 1in. radius mandrel. High speed butt weld in $\frac{7}{8}$in. mild steel plate as shown in fig. 1.

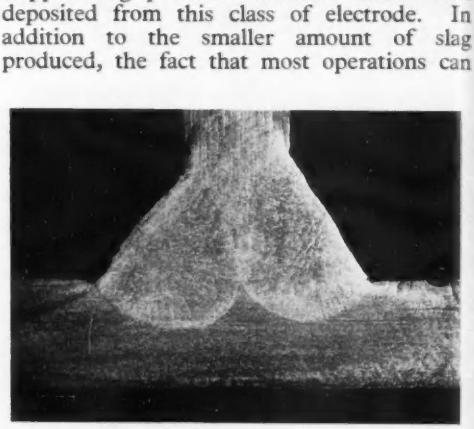


Fig. 6.—"T" weld in $\frac{3}{8}$in. mild steel plate without chamfering.

Distortion of the parent metal is also minimised by using high speed deposition owing to the greater concentration of welding heat, and an examination of the macrographs of typical high speed welds will show the area of thermal disturbance to be surprisingly small for the amount of metal deposited.

Another most important advantage of high speed welding is the ability to penetrate deeply into the parent plate and to dispense with the considerable amount of plate chamfering necessary when operating on heavy material and using multiple-runs.

Typical Applications.

Fig. 1, is a photograph of a butt weld between two $\frac{7}{8}$in. thick mild steel plates. Before welding, the two plates were tacked into position, leaving approximately $\frac{1}{8}$in. gap between them, neither plate being chamfered. A single run was then deposited on each side, using $\frac{3}{8}$in. diameter electrodes and a current of approximately 550 amperes, each run being laid down at a speed of 2 minutes per foot.

It will be seen that perfect union has been achieved, each weld having penetrated more than half the thickness of the plates, the root of the first deposit being adequately penetrated by the second run. Comparing this with a normal multi-run weld, it will be appreciated that the alternative would have involved producing a double chamfer on each plate edge and depositing a small run in the root of each side. After the removal of all slag, four or more further passes would have been necessary to restore the full plate thickness, each run requiring careful cleaning before applying the next. The saving in time as a result of employing high speed welding will thus be seen to be very considerable.

It is true, of course, that during multi-run welding, successive layers of deposit have a refining effect on the grain structure of those beneath, and that the grain size of metal deposited in single runs is coarse by comparison. (Refer to figs. 2 and 3). The fact remains, however, that connections made by high speed welding exhibit extremely good mechanical properties, and the tensile and fatigue strength, ductility and resistance to corrosion are usually superior to those of the parent metal.

Fig. 4 illustrates a high speed welded test piece similar to that shown in fig. 1. The fracture occurred at a load corresponding to 29·1 tons/sq. in., and took place at a distance of 6 ins. from the weld. The slight reinforcing of the plate thickness at the weld was deliberate, as in most practical applications this would represent the normal contour.

Fig. 5 shows the result of a bend test on a high speed butt weld taken in accordance with British Standard Specification 709, 1940. Izod impact values of the order of 50 ft.-lbs. are obtainable from samples butt welded by high-speed welding. Where high impact resistance is a necessary requirement, it is usually desirable to deposit a further light run over the second in order to obtain a more uniform grain structure throughout the full section of the weld.

The "T" weld shown in fig. 6 is another example of the degree of penetration which is possible with this technique. The two ⅝in. plates were close connected without chamfering and were welded with a single fillet on each side. Complete fusion has been secured and an adequate throat thickness provided with a minimum amount of deposited metal. The alternative method would have necessitated double chamfering with three or four runs on each side, which would not only have taken several times as long to complete, but which would have consumed at least twice as much electrode material for a given operation.

It is necessary to emphasise the use which can be made of the penetrating characteristics of the high speed arc in eliminating the necessity for chamfering and other forms of plate preparation. In these days gas-cutting plant is generally utilised to its maximum capacity, and any increase in fabrication by welding will necessarily throw an extra load on to it. Any relief which can be obtained by eliminating work which otherwise would have to be carried out by this means must be regarded therefore as of primary importance. This should be borne in mind when comparing high speed welding with other methods involving additional plate cutting.

The Case for Manipulation.

Since the pool of metal produced during high speed welding is considerably larger than that involved in multi-run welding, it will be realised that this would be difficult or impossible to control if the work were inclined at any appreciable angle. This implies that, in order to take full advantage of high speed welding technique, all connections should as far as is practicable be completed in the horizontal downhand position.

With small fabrications, this is usually achieved without difficulty, but larger components naturally present certain problems in handling. Some reluctance existed, particularly in this country, to the adoption of a technique which involved a considerable amount of manipulation of large units, and this was one reason for the somewhat

Fig. 7.—Butt weld performed entirely in the downhand position, suitable for deck plating and tank tops, bearer acting as butt strap to avoid overhead welding.

slow progress made by the process in Great Britain until comparatively recently.

In the United States, however, and within the last few years in this country also, manufacturers have recognised that the advantages offered by downhand welding were great enough to justify the expense of installing plant to manipulate components being fabricated, in order to allow all welding to be performed at the maximum speed.

These manipulators are often quite simple, inexpensive pieces of apparatus, though none the less effective, but for larger work may be massive motor driven constructions capable of handling hundreds of tons of steel work. Several well known British firms now manufacture this equipment, and an increasing number of the medium sized units are being employed throughout the country. Figs. 8 and 9 illustrate one such unit having a capacity of 1 ton.

Fig. 10 is intended to show the extent of the application of this principle. In the shipyard indicated the increased speed obtainable from downhand welding made the manipulation of the whole ship's framework a justifiable undertaking. As previously stated, however, expert direction in the design stage can do much to eliminate positional welding and to reduce the amount of manipulation required.

Fig. 7 indicates a type of butt weld suitable in the shipyard for deck plating and tank tops, which by employing an appropriate bearer to act as a butt strap enables the weld to be completed from above. The plates shown are $\frac{5}{8}$in. thick and are welded without pre-chamfering in two runs, the first of which will be seen to have penetrated deeply into the bearer.

The high speed welding referred to in the preceding notes is performed manually with currents up to 600 amps. or a little more. This has been found in practice to be somewhere near the limit for hand operation. Correspondingly higher speeds are, however, obtainable with automatic plant, and in suitable circumstances welds may be made by this method using currents of the order of 2,000 amps.

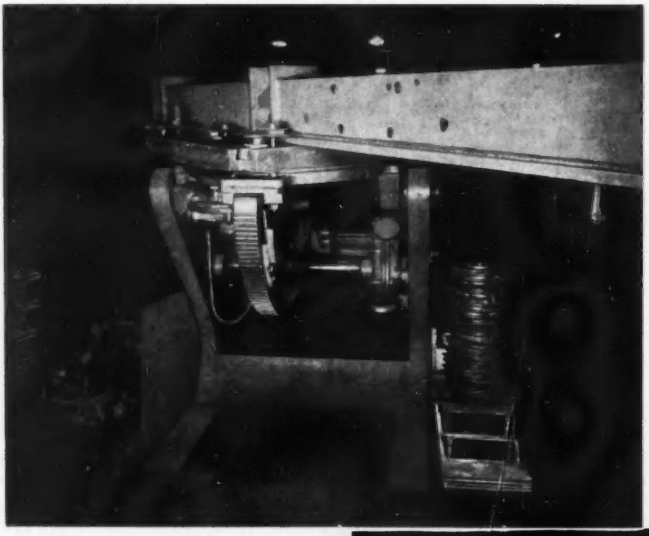
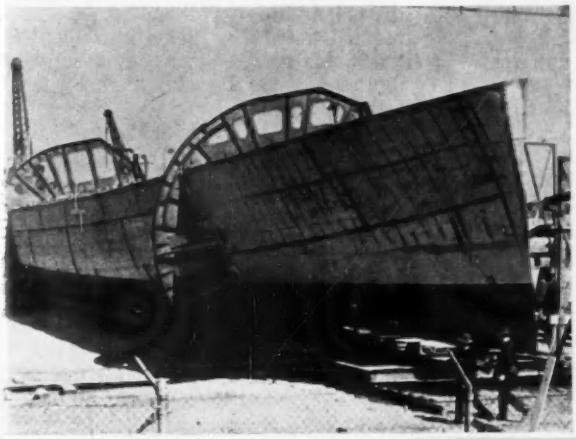
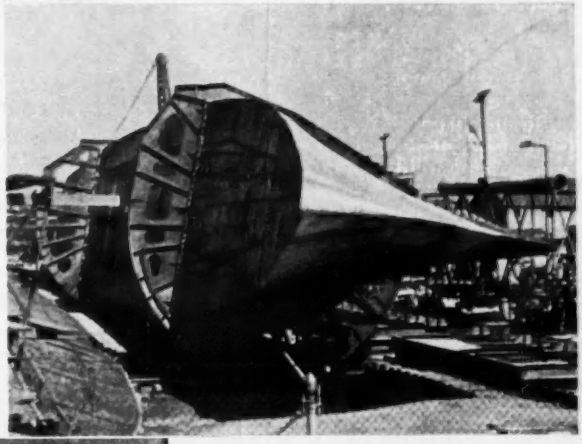


Fig. 8.—(Above) 1-ton motor driven manipulator with push-button control.

Fig. 9.—(Right) Heavy transformer clamp plate being welded on the manipulator shown in fig. 8. All fillets are being deposited in a single run in the downhand position.



(a)



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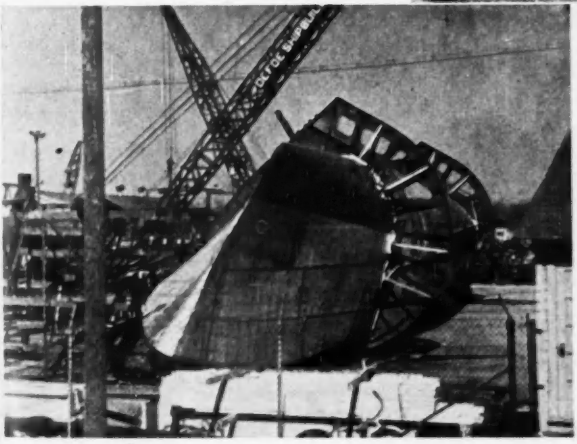

(c)

Fig. 10*.—(a, b and c) Scenes in an American shipyard showing manipulation of an entire ship's hull to enable welding to be performed at maximum speed in the downhand position.

PLANT FOR MANUAL HIGH SPEED WELDING.

High speed welding can be performed with either D.C. or A.C. at the arc, but for the following reasons where new installations are contemplated A.C. is generally to be preferred :—

1. With the tendency to use currents appreciably in excess of 300 amps. the magnetic or "blow" effect associated with the D.C. arc tends to make arc control difficult, particularly near plate edges and changes of plate section.
2. The installation cost of A.C. plant is less than that of the equivalent D.C. plant.
3. The running cost of A.C. plant may be only half that of similar D.C. plant.
4. A.C. welding plant, being static, is more robust and requires negligible maintenance.

When completely portable engine driven plant is required, however, D.C. sets are usually more practicable, as is also the case when only D.C. mains supply is available.

When A.C. plant is contemplated for high speed welding some care is necessary to ensure that suitable characteristics are obtainable. The transformer secondary voltage should be considerably higher than that used for multi-run welding in order to maintain the stability of the arc during deep penetration.

It is well known that the stability of an A.C. arc varies inversely with the power factor of the supply to it. As the arc lengthens during increasing

* Reproduced by the courtesy of Gaumont British News.

penetration, the arc voltage which is in phase with the current increases and the power factor of the circuit including transformer and stabilising reactance unit rises and brings the transformer secondary voltage in closer phase relationship to the arc current with consequent loss of stability.

In order to maintain steady arc conditions during deep penetration with currents of 500 to 600 amperes and arc voltages of 40 to 45 volts, it is sometimes advisable to use transformer secondary voltages up to 110 volts instead of the more usual value of 75 to 85 volts. The actual value required is, however, dependent on the type of electrode used and the degree of penetration necessary.

In order to eliminate interference between welders, single operator plant is to be recommended wherever practicable, and in these cases sets of 300 ampere capacity normally prove to be satisfactory, being used singly or in parallel to suit the work undertaken. For shipyard and similar installations, however, multiple-operator transformers with external current regulating reactors are advisable in order to simplify cabling problems, and in these circumstances precautions must be taken to reduce the impedance of the welding supply cables to the lowest practicable value to minimise interference.

The selection of the correct type of welding plant for a given duty should be a matter for careful consideration, and here again expert guidance should be sought from specialists.

It is also urged that unsuitable existing plant should be replaced in the interests of production efficiency by equipment designed to provide the characteristics necessary to achieve maximum welding speeds.

CONCLUSIONS.

It is suggested that in view of recent developments in connection with electrodes and arc welding plant which have been responsible for the results achieved by high-speed deep-penetration welding technique, engineers would be well advised to acquaint themselves with these improved welding methods, the adoption of which would, in many instances, result in very material benefits such as increased rate of production, savings in labour and material, reduction in cost, etc.

Where riveting or casting processes have been previously justified on the basis of comparison with fabrication by multiple run arc welding, it would now be advisable to reconsider existing policy, taking into account the increased welding speeds obtainable by the use of the improved methods now available.

Some emphasis has been placed on the advantages accruing from the adoption of high-speed welding which involve manipulation of the work, but where this is found to be impracticable, positional welding with modern plant and electrodes may result in valuable economies compared with riveting.

Another aspect which should be borne in mind is the possibility of introducing fabrication by welding as a supplement to present output which is being attained by other methods. This has already achieved encouraging results in certain shipyards.

It has not been possible in the foregoing notes to do more than suggest briefly some of the directions in which the introduction of fabrication by arc welding, or the adoption of high speed technique in place of less efficient methods, might assist the country's productive effort.

However, they will have served their purpose if they have succeeded in indicating the trend of modern arc welding practice and thereby have been of some assistance to engineers confronted with wartime problems of construction.

Substitution among Materials used for Cable Insulation.

By HARRY BARRON, Ph.D., B.Sc., A.I.C., A.I.R.I.

Plastics Department, Pirelli-General Cable Works, Ltd.

INTRODUCTORY.

SOMEHOW there has always been an implication of inferiority about substitution. This certainly does not apply to cable insulation where substitution is concerned with an upward trend in performance.

The problem of substitution among materials in the normal way involves considerations of performance and price. Many materials have been making considerable headway for cable insulation owing to their intrinsic properties, in spite of their high cost. The present artificial conditions merely increase the tempo of their application. For the purposes of this article it is proposed to confine attention almost exclusively to the question of performance. In any event, if by their greater resistance to service conditions, materials improve the reliability of electrical service, involve less replacement, and give longer service life, then higher cost is no impediment. All the materials mentioned are commercially available, and are used.

In effect, the whole matter really comes down to a consideration of the use of synthetic materials—synthetic elastics and thermoplastic synthetic resins. Actually there is no line of demarcation between these types of materials in the field of cable insulation, for they overlap, *i.e.*, some materials are both synthetic elastics,[1] and synthetic resins; perhaps the best example is polyvinyl chloride. A considerable proportion of the development work in recent years aimed at improving insulation has been concerned with these synthetic materials. In fact, much of the progress of synthetics has been due to this work on insulation. While comparatively few have the high electrical characteristics necessary for insulation, many others are excellent for protective sheathings.

One of the great problems of substitution is to replace rubber. Hitherto in this instance the urge has been to overcome the unsatisfactory properties of rubber. Rubber often requires external protection which takes the form either of treated fabric or of a lead coating. Both these types of protection have disadvantages. Fabrics are subject to rotting and other forms of destruction, while lead, apart from the weight aspect, is suspectible to corrosion.

Another great problem is to find substitutes for silk, paper, and cotton, which is also coupled with the necessity of obtaining improved performance. Another aspect is the urgent need to replace various drying oils and natural resins in lacquers and varnishes, a search which is also bound up with the desirability of improved performance.

A brief survey of the position may best be made by considering four main fields of cable insulation: high voltage, high frequency, medium and low voltage. Many materials have sufficiently good characteristics to find application in more than one field of cable insulation.

It is obviously possible in a short article to survey only briefly the leading features of the subject. There is no question of attempting an exhaustive study of the different materials. Each angle has already a very considerable technical background which merits much closer attention than can be given here

SUBSTITUTION IN THE HIGH TENSION FIELD.

In the field of power transmission, for cables working at high voltages, substitution of the materials used for many years has not yet progressed very rapidly. Ceramic insulation and air are the leading forms of insulation for overhead lines, while underground cables still consist, in the main, of stranded copper conductors, surrounded by numerous layers of paper, the whole system, after vacuum treatment, being impregnated with mineral oil. The cable is sheathed in lead. Chief requirements called for are low dielectric loss and high dielectric strength. The main urge for sub-

stitution in this instance is the desire for a more simplified, direct form of production. Relatively few synthetic materials have the requisite characteristics.

Polystyrene, polythene and polyisobutylene are the leading materials that have been considered. They are all hydrocarbon polymers with extremely fine electrical properties (fig. 1). However, they all suffer from some disadvantage, chiefly in their mechanical properties. Polystyrene is brittle, while polyisobutylene, although elastic, suffers from cold flow. The use of plastic materials introduces in a more intensified form the problems of ionisation, etc. Nevertheless, these materials are already extensively employed as accessories in power cables. Polystyrene,[2] in particular, is used in cable joints for barriers, as terminations, and so on. While the progress of substitution in this field of activity is necessarily slow owing to the arduous conditions to be fulfilled, yet the trend is quite clearly defined.

Although the chief effort has been to produce a new type, the wholly synthetic-insulated power cable, there has been a considerable amount of work in modifying the existing forms. Many synthetic materials are available as sheets and tapes, generally transparent and colourless, and possessing good electrical characteristics. Cellulose derivatives, and notably ethyl cellulose, have been the subject of much work in this direction. But many other very different synthetic materials have received attention, such as polythene, polyvinyl formal, rubber hydrochloride, etc.

Although the elimination of the lead sheath would have much to commend it, no great success has yet been met by the many efforts directed at substitution by synthetic materials. Among materials which have been considered are polyacrylic esters[3] and polyvinyl chloride.

HIGH FREQUENCY.

In many respects the field of high frequency and ultra-high frequency may be regarded as new, and consequently represents more a case of innovation rather than substitution. In the sense that coaxial cables tend to replace the conventional type of paper insulated cables, substitution has occurred. This is particularly the case in the branch of high frequency communication. The desirable features are to have a dielectric with as low a dielectric constant and as low a power loss as possible. Although air is unapproached as the best medium, yet the mechanical requirements

TABLE 1.
Commercially Available Materials.

Material	Chemical Composition	Usage	Application
Neoprene	Polymer of chloroprene	Extruded or calendered. Vulcanisable	Insulation or sheath
Perbunan	Copolymer butadiene and acrylic nitrile	Ditto	Sheath
Hycar O.R.	Ditto ditto	Ditto	Ditto
Chemigum	Ditto ditto	Ditto	Ditto
Buna S	Copolymer butadiene and styrene	Ditto	Insulation
Thiokol	Ethylene Polysulphide	Ditto	Sheath
Butyl Rubber	Copolymer Polyisobutylene and butadiene	Ditto	Insulation
Polyisobutylene	—	Thermoplastic Extruded	Insulation
Polythene*	Polymer of ethylene	Ditto	Ditto
Polystyrene	Polymer of styrene	Ditto	Ditto
Koroseal	Polyvinyl chloride	Ditto	Insulation and sheath
Welvic*	Ditto	Ditto	Ditto
Chlorovene*	Ditto	Ditto	Ditto
Vinylite	Copolymer vinyl chloride and vinyl acetate	Ditto	Ditto
Ethyl Cellulose	—	Thermoplastic Extrusion. Also as lacquer and as foil	Insulation and Enamel coating
Cellulose Acetate*	—	Ditto	Ditto
Formvar	Polyvinyl formal	Ditto	Ditto
Nylon	Polyamide	Ditto	Ditto

* All except these made in the U.S.A.

and practical considerations involve the use of other dielectrics.

In general the polymerised hydrocarbons, polystyrene, polythene, and polyisobutylene, are the most widely employed, and there is already a tendency to refer to these as the high frequency dielectrics. Where conditions permit, every feasible device has been employed to ensure as much air present as possible, utilising the synthetic material so as to give the requisite mechanical stability. Thus polystyrene has been used in the form of small moulded spacers, as moulded beads, as tape, as thread, and so on. By virtue of their excellent electrical properties these hydrocarbon plastics, and compositions based on them, are also successfully employed as homogeneous insulations. In these instances the material is simply extruded directly over the central conducting wire. The mechanical properties are then sufficiently good for the remaining processes, *e.g.*, screening, etc., to be carried out without difficulty.

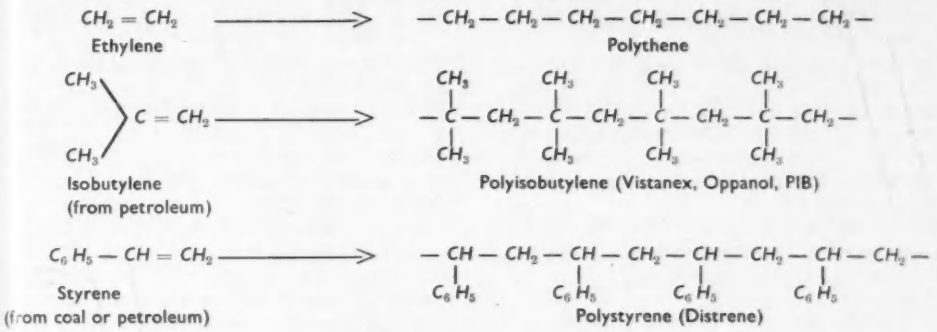

Fig. 1.—Composition of hydrocarbon dielectrics.

MEDIUM AND LOW VOLTAGE.

The most spectacular examples of substitution have occurred in the very wide field of insulation where rubber has hitherto reigned unchallenged. Although shortage of rubber has necessarily had an accelerating effect on the use of substitutes, yet quite a number had already made much headway in the realm of medium and low voltage cables.

SYNTHETIC ELASTICS.

There are already numerous synthetic elastic and thermoplastic materials possessing properties which qualify them for application as insulation of sheathing. Many of these are commercial materials, and they fall into several well defined classes :

(*a*) *Elastomers*, which is the term applied to those materials resembling rubber in composition, and in their mechanical behaviour. These include materials such as Buna S, Perbunan, Hycar, Chemigum, and Neoprene.

(*b*) *Thioplasts*, which are materials based upon ethylene polysulphide, include such well-known materials as Thiokol, etc.

(*c*) *Elastenes*, which are pure hydrocarbons based upon olefines, for example, poly-

TABLE 2.

Electrical Characteristics of Super Dielectrics (Compared with Pure Rubber).

	Polyisobutylene	Polystyrene	Polythene	Rubber
S.G.	0.91	1.05	0.93	0.91
Dielectric Constant. 60 cycles ..	2.3	2.5	2.3	2.37
Breakdown volts per mil.	600	700	1000	1000
Volume Resistivity ohms/cm³ ..	10^{18}	10^{17}	10^{17}	10^{17}
Power Factor 1000 cycles	0.0004	0.00015	0.0005	0.0016

isobutylene, polythene, and the material known as butyl rubber. In this category we may also include polystyrene.

(*d*) *Ethenoid Resins*, which are synthetic resins based on ethylene, including such as polyvinyl chloride, polyvinyl formals, acrylic esters, polystyrene, etc.

In addition to these there are a number of other materials which have limited elastic properties, and are used for various types of insulations. These have been referred to as Elastoplasts. These include materials such as ethyl cellulose, benzyl cellulose, alkyd resins, polyamide resins, etc.

There is one sharp division between these various groupings, namely, the first two types are vulcanisable, that is to say, when heated, they change from the plastic state to the elastic state, in this respect resembling rubber, whereas the other types are thermoplastic, and once applied as insulation need no further treatment.

SUBSTITUTION OF RUBBER.

The following properties account for the extensive use of vulcanised rubber:

1. It is a thermoplastic material that can be easily formed in a desired shape, which, after vulcanisation, becomes permanent.
2. It is elastic rather than rigid.
3. Normally it is a freely available material.
4. It has excellent electrical properties for insulating purposes.
5. It has good moisture resistance.
6. It has good natural ageing and moderate weather resistance.
7. It can be made tough and wear-resisting for protective purposes.
8. It is not susceptible to changes of temperature in the ordinary range.
9. It is resistant to the effects of many of the common chemicals.

On the other hand vulcanised rubber suffers from a number of defects which tend to limit its field of application. It is too versatile in its properties. The result is that it has many good properties which are not, however, outstanding. The defective properties become increasingly significant as industrial requirements become increasingly exacting. Thus rubber has comparatively little resistance to oils, greases and solvents which make it swell and lose its strength. It is strongly affected by sunlight and ozone, which cause rapid deterioration, while it tends to age under the influence of oxygen. It is extremely sensitive to minute quantities of metals, such as copper, manganese, etc. These disadvantages have encouraged the use of substitute materials. As a consequence, materials which can withstand the influence of ozone, oil, chemical attack, and sunlight, have been making headway.

Another grave disadvantage is the inflam-

TABLE 3.

Maximum Tensile Strengths and corresponding Elongations.

	Unvulcanised		Vulcanised pure gum compound		Vulcanised carbon black compound	
	Tensile strength kg/cm²	Elongation per cent	Tensile strength kg/cm²	Elongation per cent	Tensile strength kg/cm²	Elongation per cent
Natural rubber	25	1200	290	710	350	650
Neoprene	30	1100	300	820	290	760
Buna S	—	—	—	—	280	650
Perbunan	—	—	150	900	320	600
Hycar OR	—	—	48	540	300	510
Butyl rubber	—	—	250	1000	—	—
Thiokol A	—	—	—	—	60	370
Thiokol D	7	570	35	750	120	610
Polyisobutylene (Low molecular weight)	20	1000	Not Vulcanisable		Not Vulcanisable	
Polyisobutylene (High molecular weight)	60	1000	Not Vulcanisable		Not Vulcanisable	
Koroseal 0% plasticizer ..	400	2	Not Vulcanisable		Not Vulcanisable	
Koroseal 30% plasticizer..	270	170	Not Vulcanisable		Not Vulcanisable	
Koroseal 60% plasticizer..	70	500	Not Vulcanisable		Not Vulcanisable	
Polyvinyl chloride 50% T.C.P.	160	350	Not Vulcanisable		Not Vulcanisable	
Vinylite 33% plasticizer..	210	300	Not Vulcanisable		Not Vulcanisable	
Polyvinyl formal	300	100	Not Vulcanisable		Not Vulcanisable	

nability of rubber, as a result of which short circuits or overloading may cause it to catch fire. A very important advantage of most synthetic materials over rubber is the fact that in many cases it is not essential to use tinned conductors.

The following materials are of outstanding interest in this field of activity.

Buna S.

Buna S[4] is a brown rubbery material resembling raw rubber (smoked sheet). It is a

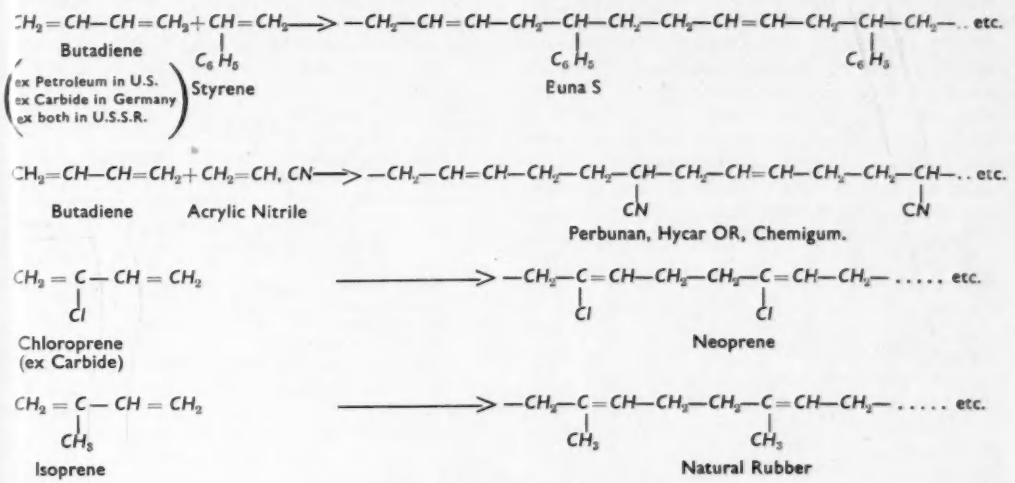

Fig. 2.—Composition of elastomers.

The position can be briefly summarised as follows :—

Natural rubber is superior in :

1. Processing properties.
2. Extensibility (in most cases) and elasticity.
3. Resilience (*i.e.*, low hysteresis loss).
4. Maintenance of elastic properties at low temperature (in most cases).

Synthetic elastic materials are superior in :

1. Resistance to deterioration by oils and organic solvents.
2. Resistance to oxidation or ageing.
   (*a*) Induced by actinic rays (sunlight, etc.).
   (*b*) Induced by heat.
   (*c*) Induced by strong oxidising agents or metals.
3. Lower permeability to gases and liquids.

An essential feature of successful substitution is that whatever materials are used, they should be capable of being processed on standard existing equipment, so that any mixing procedure should be carried out on open rolls or internal mixers. Normal methods of application such as extrusion, or longitudinal application, or lapping, must be practicable.

copolymer of butadiene and styrene. This elastomer is outstanding in many respects among synthetic elastic materials. It resembles rubber in possessing extremely good electrical and mechanical characteristics. It is unique among elastomers, because it is employed both for insulation and for sheathing. It is handled and processed on standard rubber equipment. From the general point of view its mechanical properties are on a par with those of rubber, while its ageing properties, resistance to heat, ozone, etc., are far superior.

Buna S is the mainstay of the German synthetic rubber production, where it is widely used for insulation. It is intended that two-thirds of the American production of synthetic rubbers shall be Buna S. As a non-polar hydrocarbon, free from the impurities usually associated with rubber, it would be expected to have good electrical characteristics. It does not possess that resistance towards oils and solvents which is the outstanding feature of other rubberlike materials. A slightly modified material, Buna SS, containing more styrene, has even better electrical properties. Fig. 2 shows the chemical composition of elastomers.

Other Butadiene Elastomers.

Among leading types of materials already having a wide commercial application, there are Perbunan,[5] Hycar OR,[6] and Chemigum.[7] Perbunan is a copolymer of butadiene with acrylic nitrile. The other materials are also said to be of this type, although there has been no disclosure of their exact composition. These elastomers have many properties in common, the outstanding being the resistance to oils, solvents, and chemical agents. In this they are far superior to rubber, for they withstand mineral, vegetable, and animal fats and oils, aliphatic hydrocarbons, ketones, alcohols, esters, etc., without losing their strength. The mechanical properties such as tensile strength, abrasion resistance, etc., obtained from them is very little short of the values obtained from rubber. They are superior in their ageing properties, in their resistance to ozone, and oxygen, and the way they withstand heat. They also have better resistance to moisture. As a consequence, although possessing comparatively poor electrical characteristics, they are quite widely employed as sheathing materials, to make tough oil-resisting jackets which protect the insulation. They also find application for "semi-conducting" coatings.

Neoprene.[8]

Probably the best known synthetic elastic material used for cable covering is neoprene. It is derived from acetylene. Physically it resembles rubber in many respects. It may be compounded and handled on the same plant as is used for rubber, and the methods of fabrication are likewise similar. When heated it changes from the plastic condition to the elastic, comparable with vulcanisation of rubber. The outstanding properties which have enabled it to enter the field of insulation are the excellent resistance to oils and solvents, and its outstanding flame resistance. The mechanical properties are comparable to those of rubber, products being obtained having high tensile strength and elongation, good abrasion resistance, effective tear resistance and flexing characteristics. It is not affected by chemical agents to the same extent as rubber, and also ages well. Ozone has far less effect on neoprene than it has on rubber. Its electrical properties are not particularly good, nor are they enhanced by the fact that the material takes up moisture fairly readily. It is used chiefly for sheathing purposes, for those conditions which would cause rubber to age very rapidly, thus it is employed in applications, where sunlight, oil, ozone, heat, and so forth, are likely to be encountered, such as ignition wires, etc.

It is also used in cables intended for chemical plants, machinery where much oil is encountered, etc. Up to the present time neoprene has found a ready demand in the cable field, not as a substitute for rubber, but rather as an accessory, being employed where rubber was found not to give satisfactory service.

TABLE 4.

Electrical Characteristics of Vulcanised Pure Gum Elastomers.

	Buna S	Neoprene	Perbunan
Dielectric constant ..	2.9	7.5	15
Power factor at 1000 cycles	0.0007	0.03	—
Resistivity ohm/cm^3 ..	10^{15}	10^{12}	10^8

Thioplasts.

Thioplasts form another class of synthetic elastic materials which have found some application in insulation problems. They are based on ethylene polysulphide, or comparable compounds, and are made from simple ingredients, *e.g.*, ethylene dichloride and sodium polysulphide (fig. 3). The best known commercial materials are the Thiokols. They may be compounded along the lines employed for rubber, and when heated they undergo a form of vulcanisation. These materials are much inferior to rubber in respect of their tensile properties, for example, the top value of 1500 lbs. per sq. inch is the best that can be obtained. However, in their resistance to petrol, oil, and solvents, they are unequalled by any other type of material.

The electrical properties are fairly good. Thus Thiokol A has a dielectric constant of 4·6 and a power factor of 0·005 measured at 1000 cycles; when compounded these values become 5 and 0·015 respectively, while the resistivity is $1{\cdot}6 \times 10^{15}$ ohms./cm^3. The resistance to penetration by liquids and gases is extremely high. These materials have found fairly wide employment in the United States; for example, for low voltage insulation in underground cables where the conditions are too corrosive for lead-covered cables. Thioplasts are practically unaffected by ozone, sunlight, and other ageing influences.

There are a number of types with varying properties. Thus Thiokol A has best solvent resistance and superb resistance to moisture. Another type, Thiokol D, has better general properties, in particular having a much greater temperature range, *e.g.*, it is flexible at –40

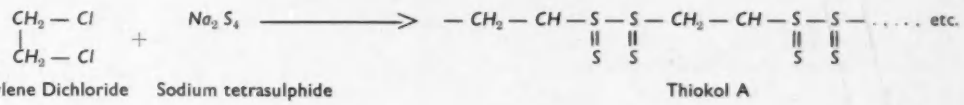

Fig. 3.—Composition of thioplasts.

degs. C. It is used for sheathing cables intended to withstand oil and heat.

THERMOPLASTIC MATERIALS WITH RUBBERLIKE PROPERTIES.

In passing from the thermosetting or vulcanisable elastic materials to the thermoplastic materials, it is perhaps desirable to outline the defects of the latter. Almost the chief disadvantage is that the plastic properties begin to show up at relatively low temperatures and flow commences with loss of shape. This problem of temperature stability is of the greatest importance. The ideal plastic for insulation would have the electrical characteristics of polystyrene, it would have the rubbery properties of plasticised polyvinyl chloride, and the temperature stability of polyisobutylene. At the present time there is no thermoplastic material even approaching the ideal. Some of the leading materials are briefly discussed.

Polyisobutylene.

This is a pure hydrocarbon,[9] completely saturated, and non-polar, and has, as a result, exceptional electrical characteristics. It is a rubbery, gristly material, which is nevertheless thermoplastic. It is flexible down to the extremely low temperature, –50 degs. C., and does not soften until well above 100 degs. C. It can be worked on the rollers just like rubber, or any of the elastomers, and large quantities of filling materials may be taken up. However, it cannot be vulcanised, and since its greatest defect is its "cold flow," there are limitations to its applications. It has remarkable resistance to every form of corrosion ; it is almost completely resistant to ozone, oxygen, heat, etc. It is swelled by many solvents which attack rubber. It is extremely resistant to most chemicals, being affected only by chlorine, bromine, and so on. It is, however, susceptible to sunlight, a defect which can be overcome by incorporating a small amount of carbon black.

It has been fairly widely used together with rubber in order to improve some of the properties of the latter, notably the resistance to ozone. Polyisobutylene also features in numerous compositions used for a variety of

TABLE 5.

Swelling of Vulcanised Compounds in Liquids.[15]

Volume increase, in per cent, after immersion for 8 weeks at room temperature.

	Natural rubber	Neoprene	Perbunan	Thiokol A	Thiokol D	Thiokol F
Light gasoline (Benzine)	160	—	20	0	—	—
Gasoline	230	8	40	0	3	3
Kerosene	—	60	—	0	2	2
Diesel oil	120	—	15	—	—	—
Fuel oil	—	—	—	0	10	10
Lubricating oil	—	40	4	0	1	1
Paraffin oil	140	—	3	—	—	—
Transformer oil	150	—	5	—	—	—
Acetone	—	25	110	—	—	9
Benzene	370	160	210	7	150	90
Carbon tetrachloride	670	160	220	0	40	30
Ethyl ether	130	50	50	—	—	—
Linseed oil	100	—	20	—	1	1
Turpentine	300	90	50	0	—	—

insulating purposes, *e.g.*, for high-frequency work, etc.

Butyl Rubber.

The Standard Oil Development Company[10] has recently developed an elastic material which is closely related to polyisobutylene (fig. 4). By introducing a small proportion of butadiene they made a copolymer which was sufficiently unsaturated to be vulcanisable. As a result, after being suitably compounded and heated, it becomes an elastic material which no longer suffers from "cold flow." This is a white, very soft rubbery material, which may be handled and compounded in very much the same way as natural rubber (fig. 5). It has excellent electrical characteristics which are quite as good as those of rubber. It has superb resistance to every form of corrosion, being quite without equal in respect to concentrated acids, such as sulphuric and nitric acid. It is virtually unaffected by ozone, by oxygen, by deleterious metals, etc. Its ageing characteristics are better than those of rubber. Another outstanding feature is the extremely wide range of temperature in which it can be used. It is flexible down to –70 degs. C. and withstands high temperature far better than rubber. It is attacked by a variety of solvents, but is extremely resistant to moisture, and has a high degree of impermeability to gases. It is already being extensively used for insulation purposes in the United States.

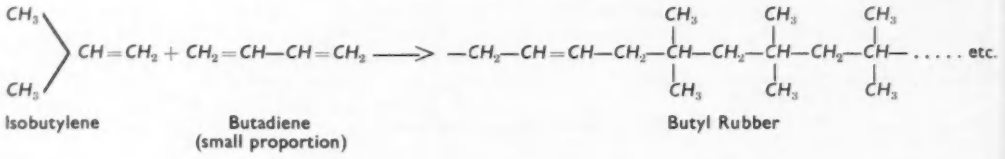

Fig. 4.—Composition of Butyl rubber.

Polyvinyl Chloride.[11]

Polyvinyl chloride is probably the most important thermoplastic material used in the cable industry. It is certainly the most extensively used. It is employed for house-wiring, switchboard wires, etc. It is used both for low tension insulation and for sheathing purposes.

In the raw condition the polymer is a white powder which may be blended with other materials, and plasticised to an elastic condition by the addition of various plasticisers. The most important of these is tricresylphosphate. This compounding can be carried out on standard mixing equipment found in rubber factories (fig. 6).

The physical properties and flexibility may be varied and are dependent upon the amount of plasticiser added. The plasticisers also have considerable influence on the electrical characteristics and the flexibility at low temperature. The great practical advantages of polyvinyl chloride include the fact that it can be extruded without difficulty on standard equipment, and once extruded, does not require any further heat treatment. It is

Fig. 5.—Mixing plastics on open rolls. Similar plant is used for rubber and synthetic elastics.

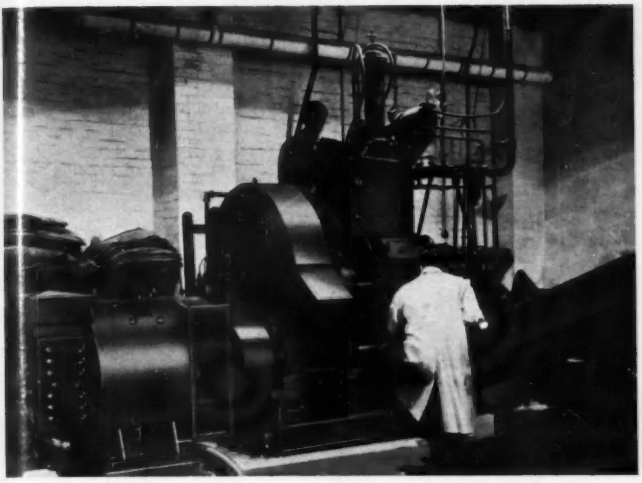

Fig. 6.—Banbury mixer employed for compounding plastics. It is also used for rubber and synthetic elastics.

extremely resistant to all forms of corrosion, being unaffected by many chemicals. It is not swelled or attacked by petrol, oils, greases, etc. It does not burn, and does not support combustion. It is virtually unaffected by ozone, and oxygen, it ages well, and has good flexing properties. Polyvinyl chloride is unaffected by sunlight. As a result there is no necessity for any further covering. It is available in every colour, either transparent or opaque. Fig. 7 shows the composition of ethenoid resins.

Closely related to polyvinyl chloride is the copolymer of vinyl chloride and vinyl acetate.[12] It contains about 5 per cent of vinyl acetate in the molecule which seems to act as an internal plasticiser. In many respects this resembles polyvinyl chloride, although it is somewhat easier to process. In general, the properties, particularly the mechanical and the electrical properties, are on a par with those of polyvinyl chloride.

Both these types of materials have similar disadvantages. As the temperature rises, so the thermoplastic properties begin to become apparent. Consequently they are not recommended for service in conditions above 80 degs. C. They also tend to be brittle at low temperatures, although this ability to retain flexibility at low temperatures, can be profoundly modified by the use of plasticisers, *e.g.*, a crack temperature of –35 degs. C., is feasible.

In spite of shortcomings, these materials find very extensive application for many classes of wiring, uses which are expanding rapidly. Possessing most of the operating advantages of rubber in ordinary insulation, they are free from most of the disadvantages. The corrosion resistance and mechanical properties are such that they are used as protective sheathing over many other forms of insulation. They are also widely used as sleevings and conduits.

PLASTIC SYNTHETIC MATERIALS USED FOR INSULATION.

There are numerous synthetic materials which possess limited elastic properties or no elastic properties, but which nevertheless find an expanding use for covering cables. Among the leading products from the electrical point of view may be mentioned polystyrene, polythene, ethyl cellulose, benzyl cellulose, polyvinyl formal, etc. In some instances they are applied and used much in the same way as are the plastic materials, chiefly by extrusion. However, many of these plastic materials are equally valuable in other forms, notably in the forms of tape or foils, as threads, or in solution.

Polystyrene.

Polystyrene is a transparent synthetic material which has exceptional electrical characteristics. Its take-up of moisture over long periods is nil, which when combined with the fact that it has high breakdown strength and a lower power factor, opens up very wide fields for its application. These are

TABLE 6.[10]

Electrical Properties measured at 1000 cycles.

Dielectric Strength kV/mil.	Butyl Rubber 0.6		Natural Rubber 0.5	
	Dry	Wet*	Dry	Wet*
Dielectric constant (1000 cycles) ..	2.11	2.10	2.46	2.76
Power factor, per cent	0.04	0.05	0.04	0.16

* 88 hours in distilled water; surface wiped dry for measurement.

TABLE 7.

Electrical Properties of P.V.C. and Copolymer.

	Dielectric Constant 60 cycles	Power Factor 60 cycles	Breakdown strength volts/mil	Resistivity ohms/cm³
P.V.C.				
No plasticizer	3.4	0.04	750	10^{13}
33% Plasticizer (T.C.P.)	7.6	0.07	500	4×10^{11}
66% Plasticizer (T.C.P.)	10.0	0.25	350	3×10^{8}
Copolymer				
No plasticizer	4.0	0.02	650	10^{14}
33% Plasticizer (T.C.P.)	4.5	0.1	350	10^{11}
66% Plasticizer (T.C.P.)	5.2	0.20	250	10^{8}

only limited by the fact that in the solid form it is a relatively brittle material, and no plasticiser has yet been evolved which gives it satisfactory physical properties during the normal working range. The usual result of adding plasticisers is to give a very soft material. It is extremely resistant to chemical attack, although it is dissolved by many common solvents.

It is extensively employed as coils, beads, bands, and foils, as a low capacity separator, for use in coaxial cables in order to hold the central conductor and maintain an air gap. Other uses are in high tension cables, where it is used as barriers to prevent flow of oil, and for making joints. It has been possible to obtain flexible threads and films of polystyrene by drawing or extruding threads of the moulded material, and extending these to several times the original length. The resulting products are quite flexible by contrast with the parent material.

Polythene.

This material has many of the advantages of polystyrene, without the disadvantages. It is prepared by the polymerisation of ethylene under the influence of high pressure and temperature. It is a tough, flexible white material which is completely insoluble in all solvents below 70 degs. C. It has a rather sharp softening point, lying between 100 to 115 degs. C. Unlike most synthetic insulating materials, it is a definite solid below the melting temperature, while above it is a very viscous liquid. It is extremely inert towards nearly all chemicals, and has exceptionally good water resistance. As a pure hydrocarbon, its electrical characteristics are excellent, almost on a par with those of polystyrene. It is usually applied as insulation by extrusion. By virtue of its electrical properties it is employed for high-frequency cables, high tension cables, and so on. It may be prepared as thin film or tape. Almost the only outstanding disadvantage is that the material can be cut and marked very rapidly, and it must therefore be protected mechanically against hard wear. It is unaffected by ozone, sunlight, and other deteriorating influences.

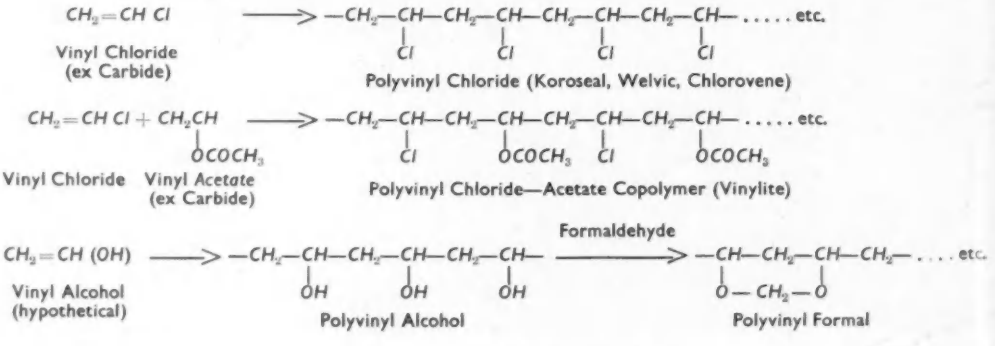

Fig. 7.—Composition of ethenoid resins.

Cellulose Derivatives.[13]

Nearly all cellulose derivatives are characterised by a tendency to take up water. The outstanding exception, cellulose nitrate, is so inflammable as to be quite unsuitable for insulation except as coatings, where the inflammability can be controlled. Although water absorption is pronounced in the case of esters such as cellulose acetate, etc., recently developed mixed esters, such as cellulose acetobutyrate and cellulose acetopropionate, are much improved in this respect. This water absorption prevents their use for solid insulation, yet cellulose acetate lacquers are outstanding as cable lacquers. The skilful incorporation of suitable plasticisers has overcome the main objection while enhancing the other properties.

carried out at relatively high temperatures makes possible the production of extremely tough insulating coatings, very flexible and durable, possessing excellent electrical properties. While the ageing properties are extremely satisfactory, yet it is attacked and dissolved by many solvents, although it is impervious to petrol and oil. The insulation is not affected by acids or alkalies.

Benzyl cellulose is a somewhat similar material having even better water resistance than ethyl cellulose, but suffering from the same disadvantage of being rather a soft material.

There have been a number of notable developments in the utilisation of cellulose derivatives for coatings, either in the form of foils, or from solutions. Materials such as

TABLE 8.

Properties of Thin Films.

Films of various materials have the following characteristics. Values on 0.001 inch films.

	Nylon	Ethyl Cellulose	Polyvinyl Formal	Cellulose Acetate	Cellulose Aceto-butyrate
Specific gravity	1.10	1.14	1.23	1.36	1.29
Refractive index	1.53	1.47	1.50	1.48	1.47
Resistivity—ohms./cm³	10^{13}	2×10^{13}	1×10^{13}	1.5×10^{11}	1×10^{12}
Dielectric strength volts per mil...	1000	1500	1000	1400	1500
Dielectric Constant 25°C. at 60 cycles	3.2	2.6	3.7	4.3	4.5
Power Factor 25°C. at 60 cycles ..	0.010	0.003	0.007	—	—
At 1000 cycles	—	0.0025	—	0.0050	0.0048
Water absorption 75% relative humidity for 24 hours..	5.2%	2%	1.3%	4.9%	1.0%

This tendency to water absorption is very much less when the cellulose ethers are considered. Hence it is found that ethyl cellulose and benzyl cellulose are both very satisfactory insulating materials.

Members of this class of products find their most important electrical use in the field of insulating coatings or as impregnating materials.

Ethyl cellulose is obtained as white granules which may be plasticised and compounded in an internal mixer, or on an open mill. By addition of adequate quantities of plasticisers, relatively elastic plastics may be obtained, which however, are comparatively soft. These are flexible down to –40 degs. C., and may be used up to 80 degs. C. However, extrusion of less plasticised compositions

butyl cellulose, cellulose acetate, cellulose acetobutyrate, which possess good electrical characteristics, are also available as films. They give films which are very much like those obtained from regenerated viscose, *i.e.*, cellophane. As in the case of paper, these may be applied by lapping on to a wire. While this procedure is comparatively simple for the larger gauges of wire, complications are introduced where fine wires are concerned.

SUBSTITUTION IN THE FIELD OF MAGNETIC WIRES.

This brings the subject of substitution into the orbit of magnet wires. These have been defined as insulated wire, generally used in the form of coils, for the purpose of interchange of electric and magnetic energy.

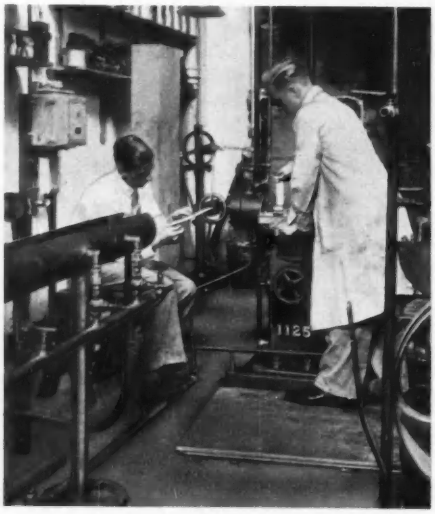

Fig. 8.—Experimental extrusion of plastics.

Insulation of such wire is of the greatest possible importance in view of the fact that every electrical machine contains coils of such wires. This class of wire is insulated with continuous films of baked enamel, or with wrappings of cotton, silk, rayon, asbestos, paper, glass, cellophane, cellulose acetate strip, etc. There are also combinations of these types.

Probably the most important is the baked enamel type, which is often further protected by one of the other forms of covering.

These coatings must have the essential properties of flexibility, extensibility, toughness, temperature stability, and satisfactory dielectric strength.

rough. The insulation must be able to stand up to the widest possible range of temperature, flexible at very low temperatures and stable at very high temperatures.

This latter consideration is one which has presented very promising opportunities for substitution, Insulation must not be affected by high humidity at high temperature. It is also very desirable that insulation should withstand solvents, since many coils and machines are impregnated with insulating varnishes and baked. There are many other corrosive conditions which may be encountered in service, depending on the application, including conditions of exposure to acids and alkalies, salt water, refrigerating liquids, etc.

Superimposed upon all desirable features is the importance of the space factor. This is almost the most important attribute of the insulation—the ability to function efficiently in the thinnest possible coating. Even minute thicknesses of coating when multiplied by the thousands of turns that may be on a coil, assume great significance in machine design and efficiency.

Obviously this is a field offering the greatest possible scope for substitution. The alternatives are to wrap thin films around the wire, to extrude suitable materials in fine coatings on to the wires, or to substitute new materials for application by orthodox enamelling methods. While the first two methods become impracticable with very fine wires, the third method is comprehensive.

Some of the most spectacular examples have been in the field of coatings applied from solutions. In this field of insulation two types of materials stand out. They are polvvinyl formal and nylon.

The success of materials in this type of application depends upon a combination of

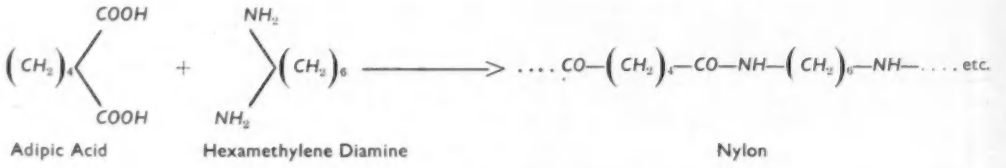

Fig. 9.—Composition of Nylon.

Since most of the wires are to be used as coils, the insulation must be sufficiently flexible to permit the wire to be wound. It must also be tough enough and possess sufficient abrasion resistance to withstand the treatment of manufacture which is often very

extremely good physical characteristics, notably abrasion resistance and flexibility together with satisfactory electrical characteristics. In both cases these conditions are satisfied. The general procedure appears to run along the lines of orthodox enamel processing, whereby

successive coatings of the solution of synthetic resin are applied to the wire until the requisite thickness is built up. It is thereafter baked at a high temperature, when the outstanding characteristics appear to be developed, the water resistance in particular being enhanced and the coatings becoming set and no longer thermoplastic.

Polyvinyl Formal.

Variations of this synthetic resin have been very successfully employed for the coating of wires. Actually, it is obtained by the treatments of polyvinyl acetate with formaldehyde in the presence of a strong mineral acid. As supplied commercially, it is available in the form of white granules. It is completely insoluble in most common lacquer solvents, in alcohol, benzene, toluene, petroleum fractions, oils, etc. It is insoluble in water. It may be plasticised with materials such as tricresyl-phosphate, dibutyl phthalate, benzyl benzoate, etc., to give plastic materials having a limited range of elastic properties. This may be extruded on wires and gives quite satisfactory insulation.

It is soluble in certain combinations of solvents, such as 70 parts benzene, to 30 parts ethyl alcohol. It can be cast from such solutions to form sheets, which can be cut into films for lapped insulation.

It is in the form of solution that polyvinyl formal finds its most important application as a substitution for enamel.[14] From dilute solutions, it is applied to the wire by methods which resemble in many respects the conventional enamelling procedure. The requisite number of coats is applied to give the desired thickness of insulation, and this is subsequently baked in order to improve the water resistance and to render it non-thermoplastic. This type of magnet wire has already attained extensive application in the United States.

Nylon.

Nylon is the material that has been developed as a substitute for silk. It is already widely employed for applications where previously silk was used. In these forms it is extruded and drawn, the latter process being essential in order to obtain satisfactory physical properties (fig. 8).

Although much has been heard about the excellent properties of filaments and fibres of nylon, little has been said about its possibilities as a coating material for wires. Nylon is a generic term for the polyamide group of materials developed by Carothers. They are formed by the condensation of long-chain aliphatic dicarboxylic acids, such as sebacic acid, with long-chain aliphatic diamines, such as hexamethylene diamines (fig. 9). As produced, they are colourless hornlike materials, specific gravity about 1·04 and having very high melting points up to 270 degs. C. They are insoluble in water and all the solvents, dissolving only in hot phenols, formic acid, acetic acid, etc. Transparent films may be cast from suitable solutions. For coating wires the material is taken up into a solution, for example, in cresol, and is applied to the wire in the usual manner. Subsequent baking treatment gives an extremely tough coating on the wire which is capable of withstanding considerable abuse.

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Industrial Diamond Wire Drawing Dies.

By B. P. DUDDING, M.B.E., Ph.D., C. G. EDEN and R. E. LEEDS.

1. INTRODUCTION.

USERS of electric lamps of the smaller wattage ratings and of wireless receiving valves rarely appreciate the fineness of the wires used for the filaments and in the construction of the grids, nor the strict control that is necessary in both the absolute diameter and uniformity of the wires.

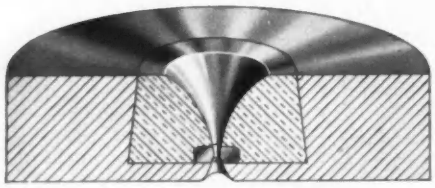

Fig. 1.—Section of a diamond die through the centre of the case (approximately twice actual size).

Tungsten filaments used in general service lighting lamps vary in diameter from 0·00055 inches in 250 volt 15 watt lamps to 0·00187 inches in 200 volt 100 watt lamps and the present-day demand in the British Isles calls for an annual production of about twenty-five thousand miles of wire in this range of sizes. The finest of these wires are about one quarter the diameter of a human hair and only a very little larger in diameter than the thread of a spider's web.

Molybdenum wire used in wireless receiving valves of the types in most common use varies in diameter from 0·0012 inches to 0·008 inches, and the annual consumption is of the order of five thousand miles.

These wires are produced by elongating the metals from a larger diameter to the required diameter by drawing through wire drawing dies. To reduce the diameter of a tungsten wire from 0·04 inches diameter to 0·0004 inches diameter the wire has to be passed through something like 75 different dies arranged in progressive steps of reduction.

In general, the diameters of these wires must not differ from an objective size by more than plus or minus 1 per cent and must not vary locally along the wire by more than plus or minus ¼ per cent. To secure this degree of accuracy, dies through which the wires are drawn must retain their size whilst thousands of yards of wire pass through them. Furthermore, as the wires are so fine the load required to pull them through the dies must be kept as small as possible, and in consequence the material used for the dies must be capable of retaining a high degree of polish.

These exacting requirements have been met by the use of diamonds of good quality but generally too coloured to be used as brilliants. For some years dies larger than 0·002 inches in diameter have been made in England and in the U.S.A., but the relatively small number of finer dies had always been imported from the Continent. A short time after the outbreak of hostilities in 1939 the situation was reviewed and a preliminary exploration of the problems involved in the production of these fine dies was undertaken. When all of the supplies from the Continental manufacturers were cut off by the enemy over-running Holland, Belgium and France, the supply of dies became a matter of urgency. In June, 1940, a thorough investigation of the problem was put in hand

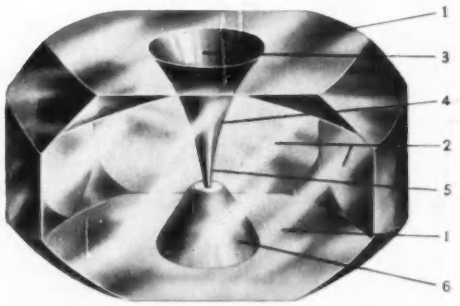

Fig. 2.—Perspective view of a prepared diamond showing the profile of the drilled hole and illustrating the nomenclature given in section 2 (approximately fifteen times actual size).

and development work commenced which aimed at a production of diamond dies in the range of size 0·0004 to 0·0015 inches in diameter.

The information available for guidance was scanty, consisting of diagrams of parts of machines in patent specifications, and access to machines producing the larger dies but known to be incapable of producing regularly, if at all, the finest dies, even in the hands of operators having years of experience. There were also some general impressions of the class of machinery and the processes used on the Continent, gained by lamp engineers during casual visits to the Continental manufacturers from whom the dies were purchased in pre-war days.

By June, 1941, machines had been designed and processes devised which experience has now shown are sufficiently under control for female operators to produce the finest dies after 3 to 6 months' experience. Very few operational errors occur which lead to the rejection of dies or to the necessity of opening them out to larger sizes. Fifty drilling machines are now installed and a production of these dies is now available.

2. DESCRIPTION OF THE DIE.

A section through the centre of a mounted diamond die is illustrated in fig. 1, at approximately twice actual size. The diamond alloy and one of many methods for doing this is described in section 3 (h) *Mounting*. A much enlarged illustration of a finished die is shown in fig. 2, and to assist in the description of the various processes involved in its production, the die has been detailed as follows :—

No.1.—Two parallel flat surfaces ground on the diamond at right angles to the drilling axis of the die aperture, and referred to as the drilling faces.

No. 2.—Two more parallel flat surfaces ground on the diamond at right angles to the first two, so that the progress of the drilling can be continuously observed. These are usually referred to as the viewing windows.

No. 3.—The entrance to the die, sometimes referred to as the lubricating cone.

No. 4.—The approach to the bearing of the die. This is conical in shape and the angle is varied according to the class of metal to be drawn.

No. 5.—The bearing of the die which determines the size of the wire drawn through it. The length of the bearing is altered according to the wire-drawing requirements of different types of metal.

No. 6.—The exit of the die.

3. DESCRIPTION OF PROCESSES.

It is convenient to consider the processes under the following headings :—

(*a*) Preparation of the diamond powder for drilling and polishing.
(*b*) Preparation of the diamond for drilling.
(*c*) Centring and starting the entrance.
(*d*) Drilling.
(*e*) Centring and rough boring the exit. This is described in detail under (*c*)
(*f*) Completing the exit.
(*g*) Polishing.
(*h*) Mounting.

(a) Preparation of the Diamond Powder.

Diamond used for crushing is usually of the lowest quality, and is unsuitable for dies because of the presence of inclusions, flaws, irregular shapes, etc. It is broken down into powder by impacts delivered on a steel plunger inserted into a suitably designed container, which is the traditional method. After crushing, the powder is screened to obtain particles which would pass through

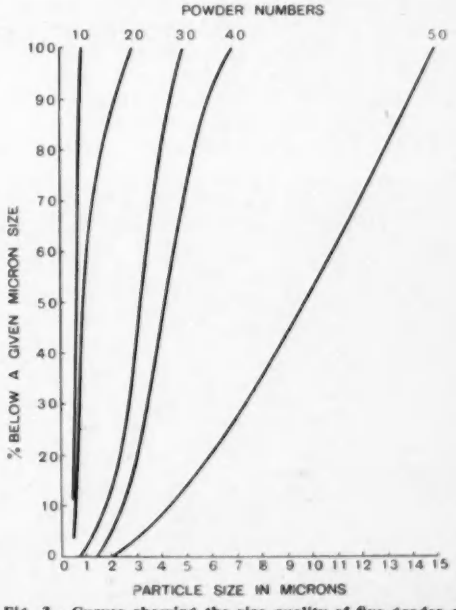

Fig. 3.—Curves showing the size-quality of five grades of diamond powder. The curve for a perfectly separated powder would be a vertical line. Sudden discontinuities in the curve indicate imperfections in the grading process. The range of powder sizes covered by these curves is from six ten-thousandths to four hundred-thousandths of an inch.

400 mesh (Tyler) sieves. Hitherto, further grading has been usually carried out by suspending the powder in olive oil and allowing it to settle, the time of settling being adjusted to produce a series of approximately five different powder ranges. To obtain the finest powders by this process the settling has to be continued for several months, and in general the procedure does not yield closely graded batches of powder. Considerable improvement has been obtained by the introduction of a centrifuge which enables the grading into separate fractions to be completed in approximately half an hour. Further it has been demonstrated that this method of separation yields powders of very much closer grading. As a result of experience to date, five different grades of powder are being produced by this method and the quality of the gradings is shown by the curves given in fig. 3, which are self explanatory

The only other departure from general practice worthy of notice is the chemical treatment of the crushed powder, either before or after grading, in order to remove any foreign material which may be present in the low quality diamond used for this purpose. The loss in weight in the cleaning process varies, and has been found in some instances to be as great as 12 per cent. That foreign material is removed has been established, and there is a marked difference in the appearance and colour of the untreated and treated powders. In addition, improved cutting or drilling properties are obtained in the fine grade of cutting powder which is essential to the making of the finest dies.

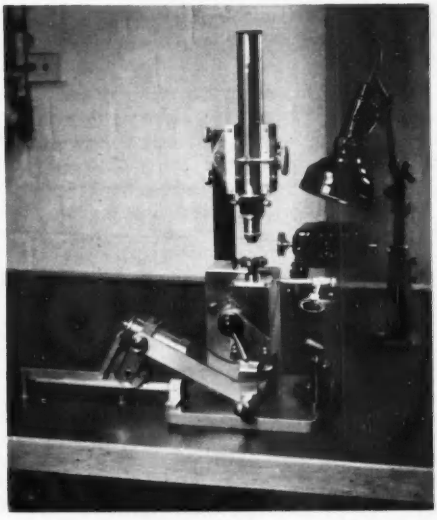

Fig. 5.—The apparatus used for commencing the boring of the entrance and, after completion of the drilling, the exit of the die. The diamond secured to the chuck on the rotating head is in this picture positioned vertically so that it can be conveniently aligned under the microscope to ensure accurate axiality, particularly when boring the exit.

(b) Preparing the Diamond for Drilling.

Before a diamond can be drilled it is usual to cut and polish two faces on the stone parallel to each other, and in the case of small dies one or two windows are cut and polished at right angles to these two faces. This operation is carried out by holding the diamond against a rotating disc of cast iron impregnated with diamond powder and spinning horizontally at a speed of approximately 2,500 revolutions per minute. The disc with the diamonds in position is illustrated in fig. 4.

A number of diamonds are processed at the same time and these are held in suitably shaped holders either with solder or by mechanical means. Great care is exercised to see that the two faces are parallel to each other to a fairly high degree of accuracy,

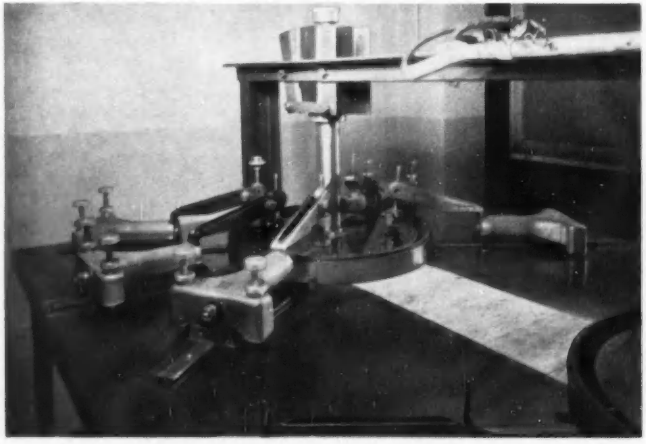

Fig. 4.—A table top view of a polishing machine with five holders in position on the revolving iron disc impregnated with powdered diamond. The holders are suitably designed for each operation on the diamonds to ensure accurate parallelism of the drilling faces and viewing windows.

and special devices have been fitted to the holders to make this operation commercially possible with girl operators. Each face is prepared separately and the time taken depends upon the orientation of the stone relative to its crystallographic axis.

It is interesting to note that diamonds fabricated as brilliants for jewellery are polished in the same way, and the surface produced is of adamantine lustre.

(*e*) Centring and Starting the Entrance.

This operation is carried out on apparatus designed primarily for process (*e*) *Centring and rough boring the exit*, and it is therefore convenient to describe these two processes simultaneously. The apparatus[1] is shown in fig. 5. Actually this apparatus is a specially designed microscope fitted with a sub-stage capable of being turned through 90 degrees and rotated by means of an electric motor. The essential feature is a stage fitted with adjusting screws so that the diamond can be placed in any desired position under the cross wires seen in the field of the microscope.

The exact position where the diamond is to be pierced is marked on one of the prepared faces with a suitable pigment, prior to cementing it with shellac to the specially shaped steel disc which fits into the stage. The mark made on the diamond face is then centred by means of the adjusting screws so that when rotated under the microscope it remains in the centre of the cross wires. The stage is then turned through 90 degrees from a vertical to a horizontal position (fig. 6) and coupled to a fractional horse power motor with foot operated speed control. To illuminate the diamond during setting up and boring, a small lamp shown in the illustration is arranged to throw a beam of light centrally through the axis of the apparatus in whichever position the stage is placed.

A small countersink is made into the diamond, and this operation has to be carried out with splints of diamonds, no other material being hard enough. These splints, as they are called, are fragments of diamond which have usually been cleft off large stones during their shaping for gems, etc. The splint is held in the jaws of small pliers and the point carefully pressed on to the face of the diamond while it is rotating. The penetration of the splint into the diamond is observed by the operator in the field of a low power lens.

When process (*e*) is being performed the diamond is already drilled from one side, and centring has to be done with the highest precision, particularly for dies below 0.001in. in diameter. The diamond is mounted with the side already drilled facing downwards, and centred to the base of the hole. It is for this reason that this process calls for close parallelism of the two drilling faces, because if the diamond is wedge shaped the high refractive index will introduce an appreciable error in the axiality of the entrance and exit of the die.

The exit is bored to approximately two-thirds its finished depth by means of splints of diamond in much the same way as the entrance was started. The exit is finally completed by transferring the diamond to a drilling machine where the two holes can be united with sufficient care to avoid splintering at the junction. The apparatus has contributed considerably to the ease with which the very difficult operation of aligning the axis of the entrance with the exit can be carried out correctly by operators having quite short experience. It is clear that fracturing the diamond at the junction of the bearing and the exit would call for the enlargement of the die. Lack of co-axiality between the bearing and exit is a fault frequently found in fine dies of Continental origin and wire drawn through

Fig. 6.—The diamond shown in the horizontal position. A conical shaped incision is bored into the diamond by pressing gently against it a suitably pointed fragment of diamond held in a pair of pliers. The progress of the operation is observed through a magnifying glass.

[1] G.E.C. Patent Specification No. 544381.

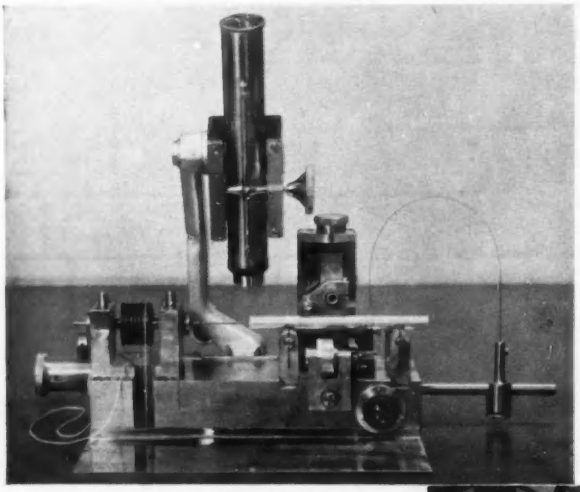

Fig. 7.—The various parts of the machine are shown in their correct positions for the drilling operation. The diamond, secured to the end of its holder, is in vibrating pressure with the point of the needle and under the microscope.

such dies is usually very "curly" and sometimes unsuited for use as filament wire. Process (*e*) is still the one calling for the greatest skill in the operators and offers scope for future development.

(d) Drilling.

The drilling of a diamond is a slow process as diamond is the hardest material known and can only be attacked with material equally as hard, *i.e.*, with diamond. The diamond to be drilled is kept in vibration and driven by a light spring against a revolving needle point. The vibration brings new powder, the actual means of drilling, to the needle point where it is driven against the bottom of the hole, thereby removing minute fragments from the diamond. The needle serves only as the carrier for the powder, and to keep the hole correctly shaped, but it wears out very quickly and must be frequently resharpened.

All of the machines used for drilling which have been seen on the Continent or in England operate on the same general principle, but they vary considerably in design. They are similar to a small lathe in the headstock of which is fitted a steel needle revolving at a speed of between 6,000 to 10,000 revolutions per minute. The diamond is mounted on a rod or tube resting on pivoted rollers, and reciprocated axially by means of a cam mechanism. Examination of the machines used in England for the larger dies suggested that the difficulty experienced in drilling fine holes was probably due to faulty design and to lack of precision in workmanship, coupled with the fact that operators were given no optical aid other than a low powered hand magnifying glass.

In the design of the machine illustrated in figs. 7 and 8, the aim has been to achieve a machine in which the correct alignment of the needle and the diamond could be obtained and readily maintained, and the operator has been aided by fitting a microscope. This machine was developed in two stages from experimental models and the experience gained with them greatly influenced the present design. For instance, the first machine built had two principal faults: the moving parts were too heavy and the diamond reciprocating mechanism permitted increasing amplitude as the needle wore away. This frequently resulted in the breaking of the fine point ground on the end of the needle unless the cam mechanism was very carefully adjusted, an operation which called for considerable skill on the part of the operator. Experience also showed that for the very finest dies it is necessary to be able to control the ratio of the time during which the needle is in contact

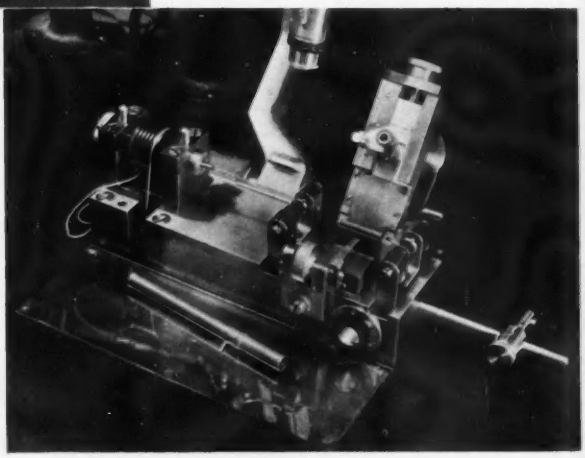

Fig. 8.—The machine with the microscope, reciprocator and bow spring swivelled out of their drilling position showing the pivoted rollers on which the diamond holder is vibrated. The various machine components are movable for convenience in removing the diamond holder, replacing and resharpening the needle, etc.

with the diamond to the time for which it is withdrawn, otherwise the very fine diamond powder used cannot move below the needle point in the time available. Many experiments with different forms of mechanism for controlling the reciprocation of the diamond were carried out before the design shown in fig. 9* was evolved. This has proved to be quite successful and provides a means for changing the time of contact of the needle with the diamond while retaining the property of constant amplitude of motion. The machine is also fitted with a micrometer screw feed which is incorporated as a means of presenting the diamond to the needle point; this feature is especially desirable when the latter is ground to a very small diameter. It also serves as a means of arresting the forward travel of the diamond after the useful point of the needle has worn away, and thus acts as a safeguard against the enlargement of the hole. As a warning that the diamond has been arrested an electric signal is provided, so that the operator can re-grind the needle point to its correct shape and size before proceeding with further drilling. In fig. 10 a subsidiary fitting is shown which enables the operator to use the headstock drive to operate specially prepared grinding and lapping wheels so that the needle can be shaped and sized under the microscope without disturbing its alignment.

The drilling process is usually carried out in three stages and different grades of diamond powder are used for each stage. The principal object in view is economy in drilling time. It is clear that when the hole is less than a thousandth-of-an-inch in diameter and the needle point correspondingly small, the diamond powder used must be fine. The particles are usually of the order of two ten-

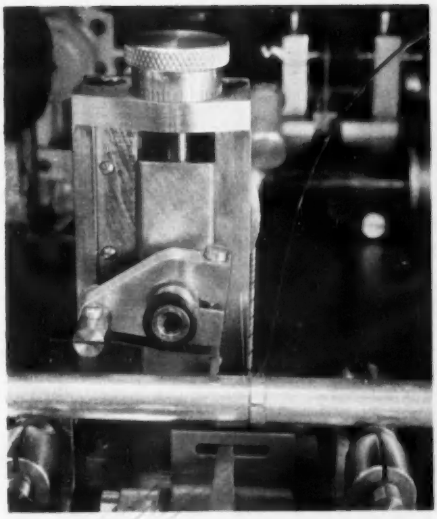

Fig. 9.—A close-up of the reciprocator, a device designed to give constant amplitude during drilling, consisting of a bent spring flexed by a small cam. By changing the cam the time of contact of the diamond with the needle point can be altered. The amplitude of the diamond holder is controlled by raising or lowering the slide to which the spring mechanism is attached, and the alteration can be measured on the engraved dial.

* Patent Application No. 1296/41.

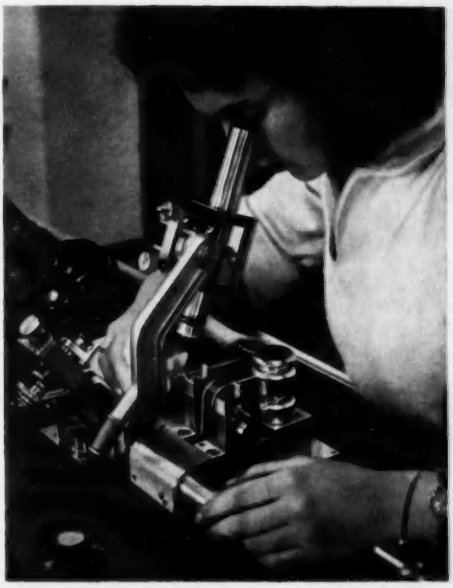

Fig. 10.—Grinding the needle to its correct shape and size with the aid of a microscope to enable the size of the point to be accurately measured. The abrasive wheel, driven from the headstock pulley via an attachment placed in front of the machine, is mounted on a taper ended spindle and manipulated while rotating at 6,000 r.p.m. on the tip of the index finger.

thousandths-of-an-inch in size. Under these conditions drilling is very slow and the needle requires attention about every five minutes. At the present time the drilling of a hole from 0·005 to 0·003 inches in diameter may take 12 to 15 hours, and one operator can attend to six or more machines, whereas the drilling of the finest dies from 0·001 to 0·0004 inches in diameter will take from 90 to 130 hours, and the operator can efficiently control only three or four machines.

(f) Completing the exit.

This calls for no special comment. As already indicated it is carried out on the

drilling machine. The amount of care which has to be exercised increases rapidly as the size of the die decreases.

(g) Polishing.

After the hole has been drilled it must be highly polished, and here again fine steel needles may be used in combination with diamond powder. The needles must, in order to reach all parts of the hole, be directed in at an angle to the die axis whether the machine is designed to operate vertically or horizontally.

The polishing of dies greater than two-thousandths-of-an-inch in diameter has presented few difficulties, and machines of traditional design but with improved details are used. In some types of machines both the needle and the diamond are rotated, either at different speeds or in the opposite direction to each other. The diamond or the needle is usually reciprocated in order to permit the circulation of the fine diamond powder used for polishing. In other types the needle is withdrawn slightly during each cycle from the rotating die while the former is rocked backwards and forwards.

Polishing extremely fine dies has presented many problems and development work is still in progress. At the moment the polishing and sizing of these dies is carried out on the type of machine used for the drilling operation.

Frequently the polishing and sizing of the die bearing is accomplished by means of a wire moved up and down through the diamond while it is rotated. Sometimes the wire is passed through the die at some predetermined angle to the die axis, or the die may be tilted relative to the wire. An experimental machine of this type is illustrated in fig. 11. On this machine a considerable amount of exploratory work has been done, thus enabling an improved design machine to be made.

Close grading of the diamond powder plays a very important part in the degree of polish obtained in the die, and it will be readily appreciated that outsized fragments will scratch the surface thereby seriously affecting the performance of the die despite its good shape.

The time taken to polish a die depends to a large extent upon the smoothness of the drilling and may vary from a few hours to several days.

(h) Mounting.

When the drilling of the die is completed, and sometimes even before it is polished, the diamond is mounted in a metal case. The case is usually a disc approximately one inch in diameter and a quarter to three-eighths of an inch in thickness. For drawing wires at elevated temperatures, steel is the most suitable metal to use. The disc is hollowed out in the centre to house the diamond which is secured into it with a suitable metallic alloy. A considerable amount of experimental work has been done to determine the most suitable alloy to use for this purpose, and the best method of using it, as under certain conditions of wire drawing the demands imposed upon it are somewhat severe. For instance, the alloy must be capable of holding the diamond securely for long periods of time at temperatures as high as 700 degrees C. during the drawing down of certain types of metal. The die must be so mounted in its case that the hole is placed centrally, and its axis at right angles to the plane of the case.

To increase the precision which is necessary for successful mounting of the finest dies a machine has been developed. This is illus-

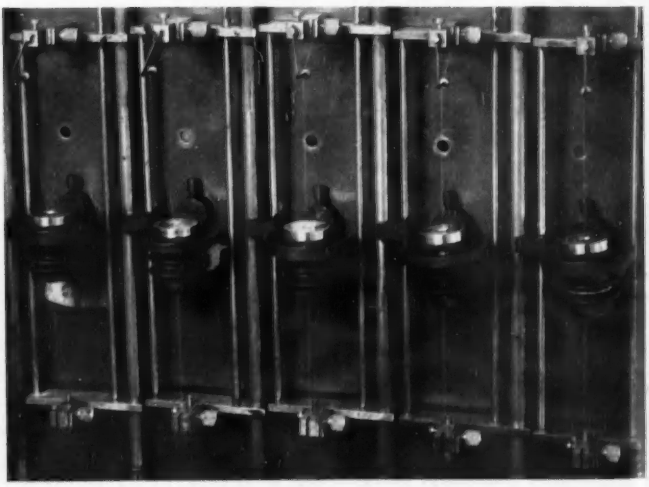

Fig. 11.—The front panel of an experimental wire polishing machine showing the lap wire coated with diamond powder. On the left side in the first two positions the wires are entering the dies at an angle while in the centre position the wire is straight. The two remaining dies are canted over at an angle.

Fig. 12.—The machine for mounting the drilled diamonds in cases. In the foreground can be seen the various components and stages of the process. On the left are the steel cases hollowed out to receive the diamonds shown in the centre. The alloy plugs which are heated and pressed around the stones are shown, and in front are the mounts as they leave the machine. On the right are dies completed by turning the cases in a lathe to their correct size and shape.

trated in fig. 12. Briefly, the case is rested on a heat insulator and the diamond located in the recess of the case by means of two tungsten needles, one in the top and the other in the bottom of the hole. On top of the diamond is placed a pellet of suitably shaped brass alloy, and by the application of heat from a ring burner and two side burners the case, diamond and alloy are heated until the latter is plastic. At this point the heat is turned off and the alloy pressed by means of the plunger provided until it completely fills the hollow in the case. It is very important that the alloy surrounds the diamond perfectly and many trials were made before satisfactory conditions were established. Excessive temperature or prolonged heating damages the polished surface of the diamond, and if this occurs it necessitates repolishing the hole which may result in its enlargement.

After the case has cooled off, the entrance and exit of the case are opened out to form a continuous contour with the corresponding portions of the hole in the diamond.

All that remains to be done is to measure the size of the wire drawn through the die, and the most accurate results are obtained when the metal for which it has been made is drawn through it with the correct wire diameter reduction, and at the normal speed, and, if hot worked, temperature. The method of measurement varies, and is made either with micrometers of varying degrees of sensitivity, electrical resistance or by weighing a known length of wire and calculating its diameter from the density of the metal concerned.

4. LAY-OUT OF DRILLING ROOM.

The general lay-out of the drilling machines is illustrated in fig. 13. The machines, arranged in banks of a dozen, are driven from a counter-shaft housed under the tables, and each machine can be controlled by means of a clutch. Adequate lighting is assured by fitting a local lamp to each machine so that the diamond is properly illuminated when examined through the microscope.

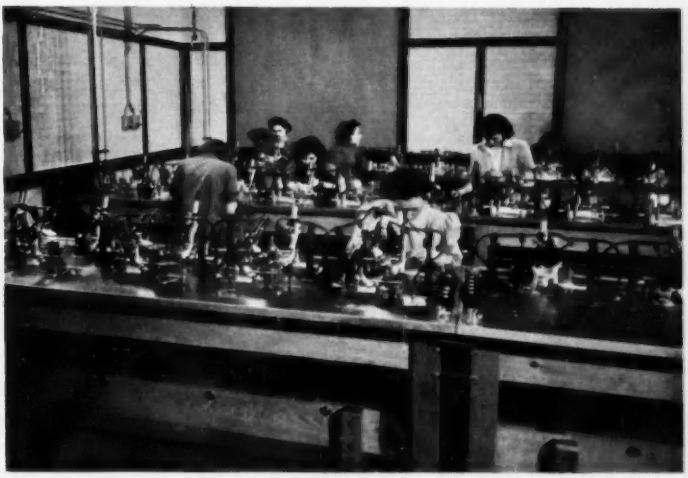

Fig. 13.—The general layout of the drilling machines. In the section shown each operator is controlling six machines.

Electricity in Paper Mills.

By W. J. MASON, A.I.E.E., and S. A. G. EMMS, B.Sc., G.E.C. Engineering Department.

PART II.

The first part of this paper, which is reprinted from the Journal of the Institution of Electrical Engineers, appeared in Vol. XII., No. 1, February, 1942, of the G.E.C. Journal.

(4) PAPER-MACHINE DRIVES.

These are the most important in the mill, and nowadays are almost always of the electric sectional type, which has obvious advantages over the older mechanical type.

The driving of the various sections of the machine would present little difficulty were it not for the fact that the sheet changes in length at different stages of the process. The pressure of the rolls causes an elongation of the sheet which exceeds the contraction caused by the removal of moisture. The net increase is usually between 5 per cent and 8 per cent and represents the difference between the increases at the couch and presses, and the shrinkage at the driers. These changes in length of the sheet are known as "draws," and they make it necessary to drive each section at a slightly different speed. In the modern unit electric drive this is effected automatically by means of apparatus known as "automatic draw control."

The following features are essential to the up-to-date unit drive :—

(*a*) The automatic draw control must be independent of the power transmitted by the driving motors.

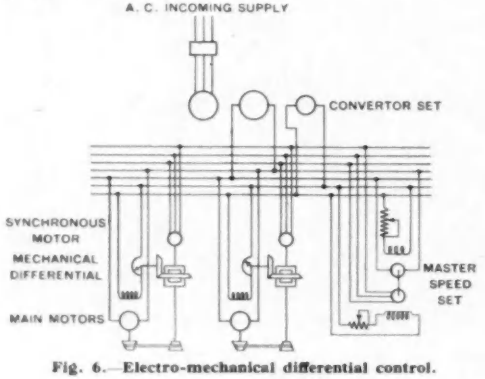

Fig. 6.—Electro-mechanical differential control.

(*b*) The draw between sections must be readily adjustable without interfering with production.

(*c*) Once adjusted the draw must remain constant, unaffected by load or temperature, over the whole speed range of the machine.

(*d*) The draw control must rapidly correct errors.

(*e*) The speed of the drive as a whole must be adjustable over a range to suit particular requirements.

(*f*) A "crawling" speed of about 60ft. per min. must be furnished to allow examination of wire and felts.

(*g*) Ability to run for long periods without maintenance.

(*h*) Suitability for working under unfavourable conditions of temperature and humidity.

As previously mentioned, the paper substance passing through the machine is extremely fragile, and the necessity for accurate speed-ratio maintenance between the various sections is of paramount importance if breakage or strain are to be avoided. This is particularly necessary in the case of high-speed machines producing at the rate of nearly 1,500 ft. per min.

In its wet state, *i.e.*, on leaving the couch section, standard newsprint has a safe tensile strength of about 0·06 lb. per inch width, and the tension produced by its own weight in the unsupported span to the press section is about 0·04 lb. per inch width. The margin of safety is thus very small, and implies that the speed control of the two sections must be accurate enough to maintain within one inch on the couch roll the point at which the paper leaves to enter the press section.

Particular care has to be taken here in order to avoid straining which seriously affects the strength of the finished product. In its finished state the paper of this type has a tensile strength of 12 lb. per inch width which is attained progressively as the moisture is expelled.

In order to obtain the required accuracy of control, the draw regulator must be extremely sensitive, and moreover it must work by comparison of angular position between each section and an independent "master," which may be mechanical or electrical. The comparison is made by some form of differential gear, which is so arranged that angular positional errors are integrated and used to effect the necessary speed correction.

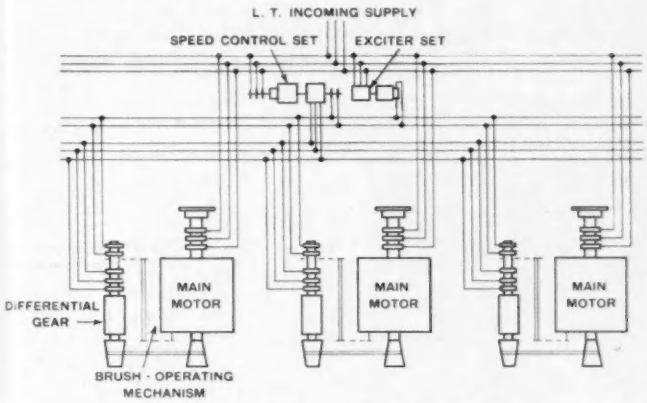

Fig. 7.—Electro-mechanical differential control with electrical differential gear.

In order to allow for the necessary "draw" between sections, a variable gear is introduced between the individual sections and the master element. This often takes the form of a pair of cone pulleys and a movable belt, or a metal chain working between expanding cones; an adjustment of $\pm$ 10 per cent is usually allowed, and may be effected by remote control from the front of the machine.

It is essential to employ the "angular comparison" principle, and not that of actual speed comparison, as an example will show. If a speed regulator having an accuracy of $\pm 0{\cdot}001$ per cent be applied to one section any error up to this value will persist, and in 100 sec. the paper will be approaching the danger point although the regulator is functioning correctly.

Four forms of sectional electric drive are in common use; three of these are shown in diagrammatic form in figs. 6, 7 and 8.

These forms are :—

(*a*) Purely mechanical control, in which the "master" element is a shaft rotating at constant speed and running the length of the machine. Each section is coupled to this shaft through a variable-speed gear (draw adjuster) and a differential; movement of the differential cage indicates error and actuates a correcting regulator.[10, 17]

(*b*) Electro-mechanical control, in which the "master" element takes the form of a 3-phase supply of constant frequency, supplied by a master conversion set. Each section has a small synchronous motor fed from the supply, which drives one end of the differential gear.

Fig. 6 shows this system as applied to a D.C. drive.

(*c*) Electro-mechanical control, with electrical differential gear. In this system a master frequency supply feeds the "stator" or outer element of a small synchronous motor; the "rotor" is driven from the section via the usual draw adjuster gear. Speed difference causes the "stator" to rotate and correct the error.

Fig. 7 shows this system applied to a 3-phase commutator-motor drive.[11]

(*d*) Fully electrical control, in which the comparison is carried out by an "electrical differential" consisting of a small machine having 3-phase windings on both stator and rotor. The stator is supplied from a master frequency set; the rotor from a "section

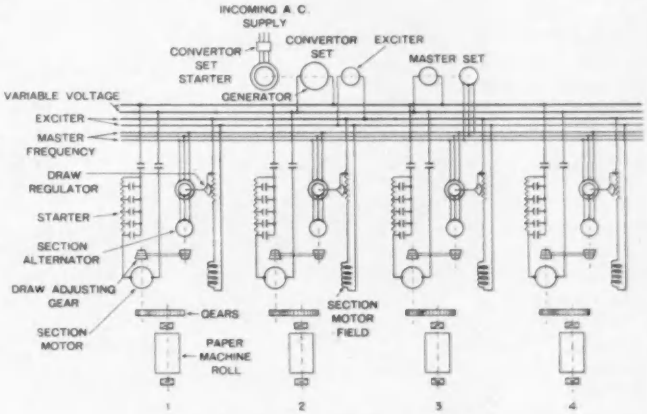

Fig. 8.—Fully electrical differential control.

alternator" driven by the section through the usual draw adjuster. While the two frequencies are the same, the rotor remains at rest; error causes the rotor to revolve and actuate a connecting regulator.

Fig. 8 shows this system applied to a D.C. drive.

As explained above, the maximum angular error which can occur between two sections is a vital quantity, and its magnitude is determined by a number of factors which fall under two heads. These are the sensitivity of the regulator, and the response of the section to the regulator. The first may be controlled by the gear ratio between the differential and the regulator, while the second is determined by the ratio of available horse-power to moment of inertia in each section.

Typical moments of inertia (in ton-ft.^{2}) of the sections of a 3-roll news machine are as follows :—

Couch	Press	Dryers	Calender	Reel
55	45	3,000	65	0·2

As the horse-power of the dryer section usually exceeds that of the others, the discrepancy is not so great as would appear. Nevertheless, careful consideration has to be given to the gear ratio between differential and regulator, and in some cases a damping device is introduced to avoid hunting.

Hunting with differential control results in alternate slackening and tightening of the paper between sections, and this passes through the machine as a wave or "ripple." Should this take place in more than one section a further ripple is superimposed on the first and is likely to result in breakage.

Some means for giving slow-running "crawling" speeds is necessary so as to allow the machine clothing (couch wire, press and dryer felts) to be examined or changed. The speed required is very low, of the order of 60ft. per min.

Where the A.C. commutator motor drive is installed this is effected by a barring motor with extra gearing, and a self-releasing clutch is introduced.

The same result is achieved in D.C. drives by introducing resistance into the section motor armature circuits. Owing to the heavy starting torques required, however, this is not wholly satisfactory, and a better solution is found in the provision of a separate auxiliary generator of low voltage. This may form part of the main converting set or may be driven by a separate motor, in which case the set is automatically started and stopped. When all section motors are running at the correct speed, the crawling set is stopped; but immediately any section is shut down the set restarts.

A view of a paper machine from the working side is shown in fig. 9, and a view of the drive side of the same machine is shown in fig. 10.

Starting Torque.

The starting torque of the various sections

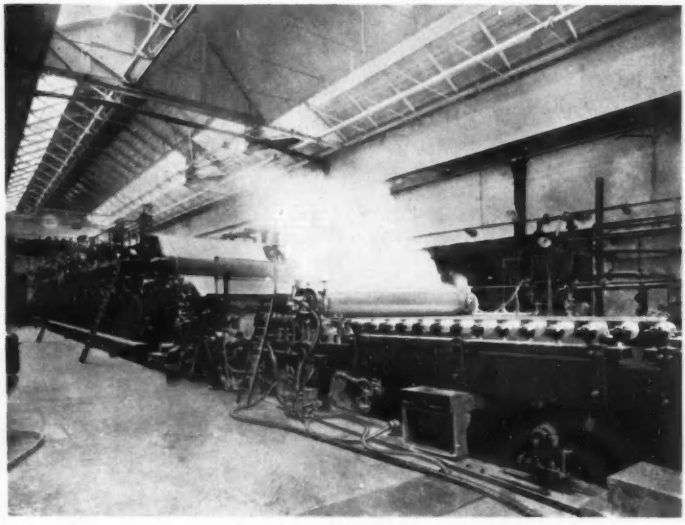

Fig. 9.—View of paper machine from the working side.

of the paper-making machine vary approximately in the ratio of 1 : 20 (the couch and presses have the lower value and the dryers and calenders the higher value). This wide divergence of starting torque considerably affects the design of the motors, reduction gears, shafts and couplings of the dryers and calenders, and in these sections the starting torque is the limiting factor in determining the size of the motor. As the calculation of this torque depends on a number of features which cannot with any certainty be ascertained beforehand, a liberal allowance is necessary in determining the size of the crawling-speed set where this is used, or in the rating of the resistances where these are employed to obtain the lower speed.

In fig. 11 is shown the torque for the various sections over a wide range of speed for a 3-roll machine. It will be seen that there is a critical velocity between 100 and 200ft. per min. where the coefficient of friction changes from dry to liquid state. It will also be noticed that torque increases with speed owing to windage. With increasing speed the power costs per ton increase, but against this there is a bigger reduction in labour and overhead costs.

The energy requirements of the paper machine at 1,000 ft. per min. amount to about 90 kWh per ton for the ordinary (Fourdrinier) process, and this is proportioned between the sections in the following manner :—

	kWh	Ratio per cent
Couch	20	23
First press	7½	8·0
Second press ..	7½	8·0
Dryers	34	38
Calender	19	21
Reel	2	2
	90	100

The curves given by fig. 12 show input (kW) at various speeds for a 3-roll newsprint machine with a constant output of paper.

Table 3 gives actual powers taken by various machines, all brought to a common basis, *i.e.*, kW per in. width per 100ft. per min. for each section.

The bulk of the power goes in machine friction. It will already have been made clear that the paper machine is extremely heavy and the difference in loading with and without paper is only about 25 per cent.

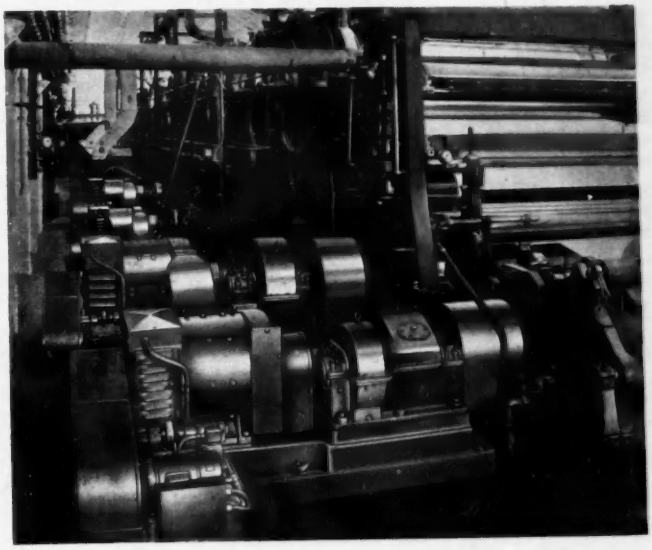

Fig. 10.—View of drive side of machine shown in fig. 9.

(5) HIGH-ACCURACY SPEED CONTROL FOR PAPER MACHINES.

The output of a paper machine has to conform closely with certain limits of weight per unit area, and as the flow of stock on to the wire is constant the speed of the machine as a whole must be controlled within narrow limits. Where the machine has a sectional drive embodying a master frequency supply the speed control is applied to the master frequency alternator.

In D.C. drives the chief causes of speed variation are voltage fluctuation and temperature change; of these the former may be relatively slight but rapid, while the latter is greater in range but takes place more slowly, and it is therefore necessary to have a system capable of responding to both conditions. Further, modern paper machines usually provide for a considerable speed range, and the speed-control system must be capable of equal accuracy over the whole speed range.

A method recently employed with success is

illustrated in fig. 13 and depends upon the comparison of two voltages, one of which is proportional to the paper-machine speed while the other is a standard independent of external conditions. The tachometer voltage is derived from a single-phase alternator which forms part of the master frequency supply set and which has either a permanent-magnet field or a controlled field current. The output from this machine passes through a rheostat mechanically coupled to the regulator controlling the speed of the paper machine and thence to a rectifier, the characteristics of the rheostat, regulator and rectifier being carefully chosen so that at any speed setting of the main regulator a constant fixed direct-current voltage appears at the rectifier terminals. Opposed to this voltage is a standard voltage which is derived from a lamp bridge connected to the mill supply, and so proportioned that its output voltage is unaffected by variations in supply voltage up to 5 per cent. These two voltages are compared by means of a supersensitive relay (shown in the figure) whose contacts, via suitable small contactors, cause a small adjusting regulator to correct the speed of the master frequency set motor.

When correctly adjusted this system is capable of maintaining speed within about 0·3 per cent under ordinary paper-mill conditions.

A still higher accuracy may be obtained by employing a more sensitive speed relay of the thermionic valve type and by introducing into the comparison circuit a factor depending upon the first differential coefficient of the speed. This factor may be derived from the secondary of a suitable transformer connected to the D.C. tachometer voltage and its presence makes possible a considerable speed-up in the response of the adjusting regulator without causing hunting.

(6) SUPERCALENDER, WINDER AND SLITTER DRIVES.

The supercalender is a machine whose purpose is to give a high finish to the paper, which is passed between a number of rolls alternately of steel and pressed paper. The only drive between these rolls is frictional and the continuous slip between them produces the calendering effect. In operation the paper is fed by hand through the rolls at low speed and is finally led round the centre of the "finished" roll, after which additional pressure is applied by means of weights to the rolls and

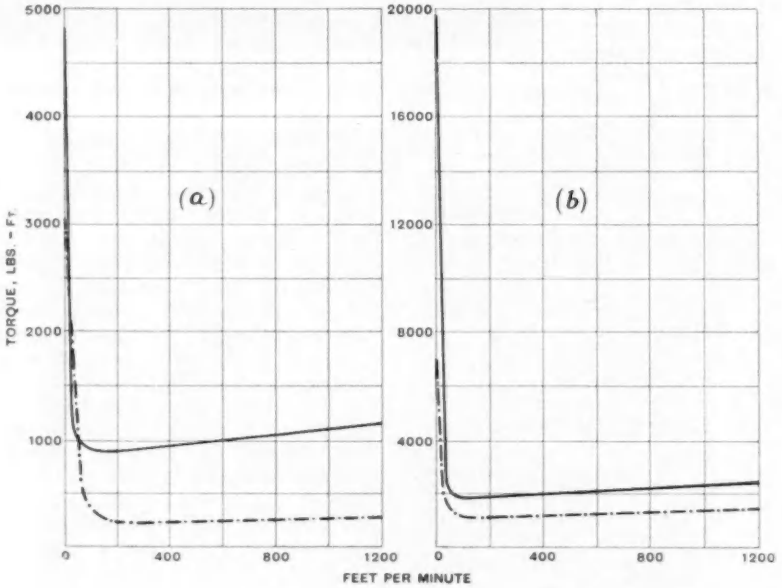

Fig. 11.—Torque for various sections of a 3-roll machine.

(*a*) — . — . 5ft. dia. single dryer.
———— 32in. dia. press

(*b*) — . — . 36ft. dia. suction couch.
———— 8-roll calender, bottom roll 34in.

the machine is accelerated to full speed. In order to avoid breaking the paper between the "unfinished" roll and the machine it is essential that the acceleration be as gentle as possible and a large number of starting steps is needed.

Should the paper break, the machine has to be brought to rest promptly without pressure on the rolls, this pressure must not be applied until the machine has been restarted, otherwise the compressed paper rolls will be dented and rendered useless; even the weight of the rolls alone causes some deformation, the extent of which depends on how long the calendar is standing, and gives a variable starting torque. This necessitates that the machine shall be capable of starting against very heavy overload torques while at the same time the normal crawling speed must not be exceeded. A low-voltage motor-generator set is frequently provided to supply the heavy current involved.[16]

In order to secure a sufficient starting torque, and at the same time ensure that the crawling speed is not too high, the control gear is sometimes so arranged that the crawl set supplies an initial current of about full-load value to the supercalender motor. Should the latter fail to start, time control is used to increase the current by steps to about 5 times full load, and should this prove insufficient the supercalender motor is shut down by its overload relay and "locked out" pending investigation. Usually, however, the supercalender motor starts before the current rises to its extreme value, and the immediate fall in current automatically reduces the voltage of the crawl generator to its correct low-speed running value.

Winder.

After supercalendering the paper passes to the winder where it is re-wound and the defective lengths cut out, and at the same time rotary knives cut it into widths suitable for its final purpose. In most cases this purpose, *e.g.*, high-speed printing, demands long continuous lengths of perfect paper, tightly wound at constant tension into rolls of accurate width, and for this reason considerable attention has recently been given to this stage of the manufacture. The winder has two drums each the full width of the paper, placed close together and driven at slightly differing speeds so that a smoothing action is obtained on the "finished" roll which is built up round a steel core resting in the space between the drums. The roll of paper from the supercalender is placed on a suitable stand which is so arranged that a brake may be applied to the reel in order to maintain constant tension as the paper unwinds. Between the unreeling stand and the drums, the paper passes between fixed knives and rotary blades driven by small motors.

Recently, various equipments have been installed in which the brake on the unreeling stand is replaced by a generator equipped to maintain constant tension in the paper as it unwinds. As the main drive to the winder drums is usually supplied from a Ward-Leonard set, it is thus possible to recover most of the energy, which is otherwise dissipated in the mechanical brake.

In order to maintain constant tension it is sufficient to maintain constant current in the

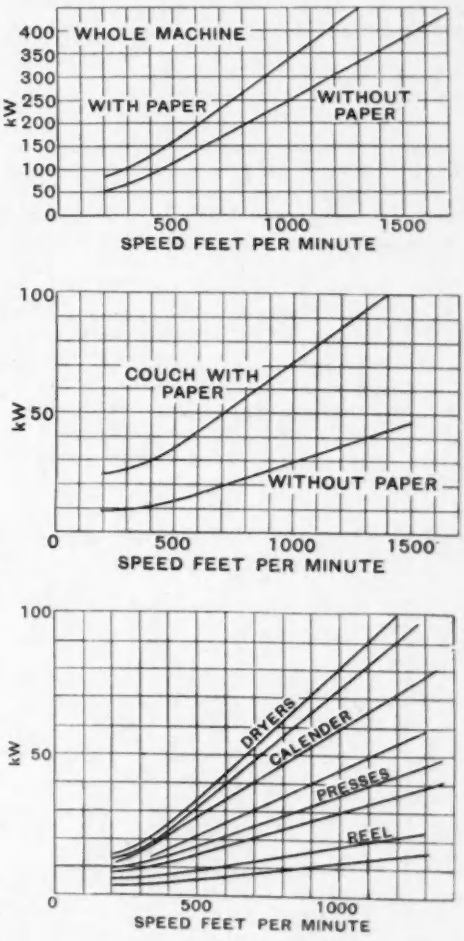

Fig. 12.—Input (kW) at various speeds of a 3-roll machine.

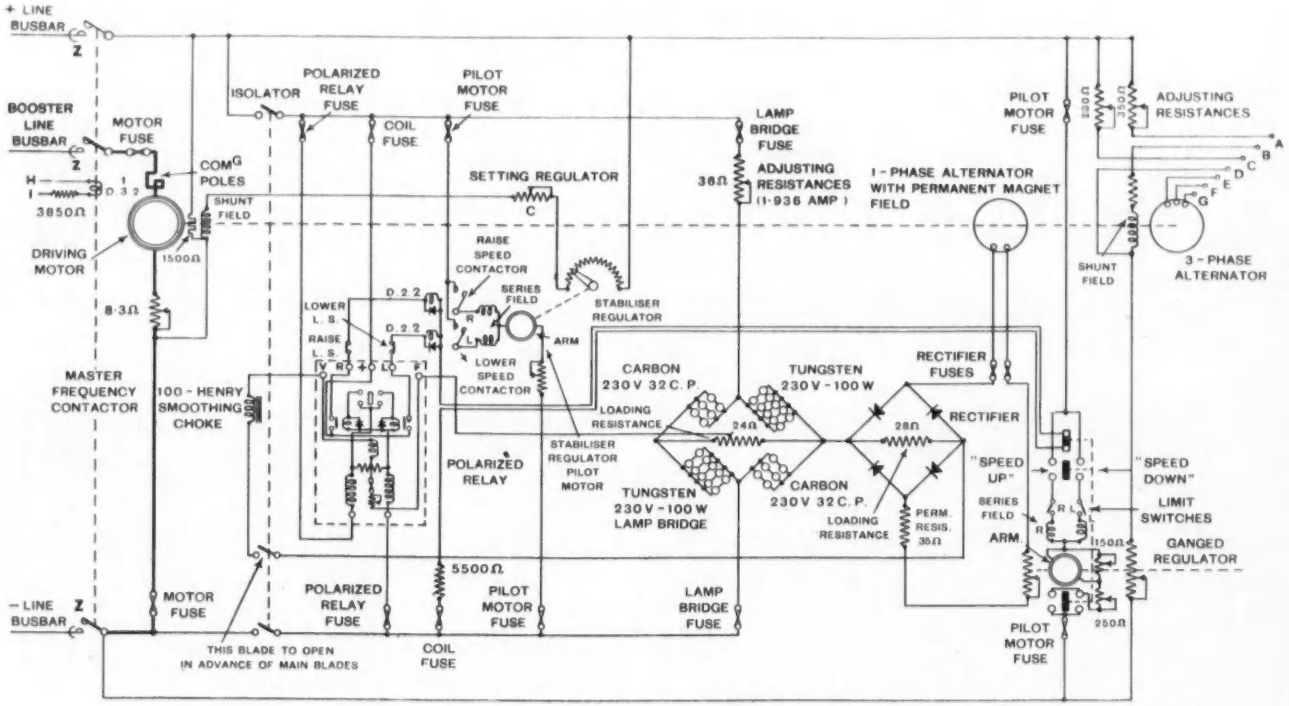

Fig. 13.—Diagram of speed controller.

generator armature, because constant speed at constant tension implies constant power, and as the power output of the generator at constant voltage is proportioned to the current, the desired result is achieved independently of reel diameter, *i.e.*, of generator revolutions. With a suitably designed generator a constant-current regulator is satisfactory for the maintenance of steady tension at fixed speeds, but compensation must be applied during acceleration or retardation so as to avoid breaking paper or throwing slack.

The application of the necessary value of compensation is extremely difficult, as the inertia of the unreeling drum progressively declines during the wind, while that of the reeling drum progressively increases. This tendency is illustrated in fig. 14, which illustrates the variation in these quantities throughout a wind.

The complete duty cycle expected from such a machine is as follows :—

(*a*) The reel generator, acting as a motor driven by the main Ward-Leonard set, slowly pays out paper from the unwinding reel.

(*b*) The end of paper, having been fed through the various rolls, reaches the new core between the drums.

(*c*) The knives are adjusted and the machine started as a whole. It is essential that the slitter motors, which are fed from the main Ward-Leonard set, shall be up to speed before the paper moves.

(*d*) After a short period at low speed the machine accelerates under Ward-Leonard control up to its maximum speed, which may be as high as 4,000ft. per min. During this accelerating period the necessary compensation must be applied so as to reduce the reeler generator armature current and maintain constant tension.

(*e*) The machine runs at full speed until either the end of the reel or a defective length of paper is reached.

(*f*) The machine rapidly slows down, still maintaining constant tension in the paper, and finally stops. After it has come to rest, the slitters stop also.

(7) MISCELLANEOUS APPLICATIONS OF ELECTRICITY.

A paper mill naturally implies means of handling the incoming bales or pulp from the ship to the beaters and breakers, and also of disposing of the finished product. Light high-speed electric cranes, in conjunction with

TABLE 3.

Average Input per Section of Electrically-Driven Paper Machines, in kW per inch width at 100 ft. per minute.

No.	Width inches	Grade of paper	Speed, f.p.m.	Couch	First press	Second press	Third press	Dryers		First calender	Second calender	Third calender	Reel	Total
								Per dryer	Total					
1	234	News	780	0.05	0.023	0.023	0.029	0.00178	0.039	0.031	—	—	0.0068	0.202
2	234	,,	1,000	0.079	0.01	0.01	—	0.0025	0.108	0.027	—	—	0.009	0.243
3	230	,,	1,120	0.0375	0.02	0.018	0.011	0.0018	0.084	0.019	—	—	0.006	0.196
4	234	,,	1,220	0.05	0.014	0.0165	0.0038	0.0016	0.068	0.025	—	—	0.01	0.187
5	234	,,	1,085	0.0515	0.0125	0.0142	0.0053	0.00165	0.076	0.036	—	—	0.007	0.200
6	234	,,	910	0.0485	0.0126	0.019	0.0265	0.0018	0.04	0.021	—	—	0.007	0.175
7	264	,,	970	0.054	0.014	0.016	0.018	0.0016	0.068	0.045	—	—	—	0.215
8	265	,,	1,150	0.057	0.016	0.016	—	0.0017	0.074	0.026	—	—	0.008	0.197
9	265	,,	1,125	0.053	0.011	0.012	0.005	0.002	0.10	0.016	—	—	0.006	0.203
10	270	,,	1,050	0.06	0.017	0.018	0.018	0.0018	0.08	0.030	—	—	0.004	0.227
11	304	,,	960	0.06	0.028	0.017	0.015	0.0015	0.07	0.06	—	—	—	0.25
12	166	,,	800	0.039	0.019	0.017	—	0.0013	0.04	0.032	—	—	—	0.147
13	164	,,	1,000	0.044	0.025	0.013	0.02	0.0009	0.031	0.024	—	—	0.005	0.162
14	160	,,	970	0.046	0.016	0.019	0.017	0.0015	0.073	0.03	—	—	0.005	0.206
15	166	,,	995	0.053	0.02	0.02	0.022	0.0015	0.06	0.03	—	—	—	0.205
16	156	Book	75	0.026	0.014	0.011	0.012	0.005	0.115	0.016	0.024	0.028	—	0.246
17	156	,,	140	0.026	0.014	0.011	0.009	0.004	0.092	0.011	0.011	0.02	—	0.194
18	154	Fine	227	0.028	0.01	0.01	0.008	0.0023	0.053	0.016	0.015	0.025	—	0.165
19	148	,,	153	0.028	0.012	0.014	—	0.0024	0.043	0.018	—	—	—	0.115
20	148	,,	245	0.03	0.02	0.017	0.019	0.003	0.100	0.049	—	—	—	0.235
21	148	,,	440	0.028	0.022	0.02	—	0.0008	0.024	0.05	—	—	—	0.144
22	134	,,	660	0.023	0.016	0.017	0.01	0.0017	0.052	0.019	—	—	0.008	0.145
23	107	,,	75	0.02	0.017	0.017	—	0.002	0.04	0.023	0.046	—	—	0.163
24	107	,,	190	0.019	0.017	0.017	—	0.002	0.053	0.02	0.03	—	—	0.156
25	106	,,	230	0.047	0.02	0.015	0.017	0.007	0.057	0.011	—	—	0.012	0.18
26	86	,,	138	0.066	0.068	0.068	—	0.0036	0.086	0.096	—	—	—	0.384
27	86	,,	400	0.046	0.02	0.02	—	0.0019	0.046	0.03	—	—	—	0.162
28	75	,,	76	0.06	0.035	0.017	0.007	0.007	0.052	0.05	—	—	—	0.22
29	75	,,	150	0.025	0.04	0.016	0.007	0.007	0.051	0.035	—	—	—	0.174
30	200	Kraft	140	0.07	0.04	0.017	0.018	0.0004	0.016	0.05	—	—	—	0.211
31	200	,,	770	0.058	0.028	0.017	0.012	0.0014	0.06	0.035	—	—	—	0.210
32	168	,,	200	0.045	0.03	0.02	0.02	0.0008	0.035	0.06	—	—	—	0.210
33	168	,,	350	0.04	0.03	0.02	0.015	0.0005	0.022	0.04	—	—	—	0.167
34	168	,,	660	0.026	0.02	0.018	0.012	0.0008	0.032	0.03	—	—	—	0.138

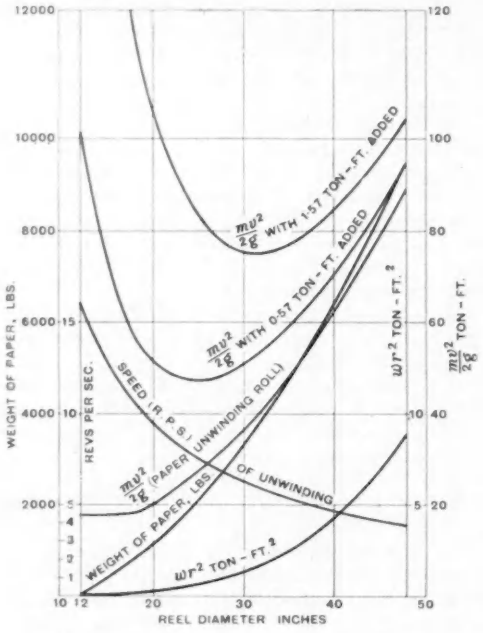

Fig. 14.—Variation of moment of inertia during a wind.

suitable lighting systems, do a great deal towards facilitating this handling, but do not themselves call for special comment.

Electric lighting, particularly when it embodies the judicious use of mercury-vapour lamps, has been found invaluable in the sorting and grading department.[14] Electricity is also employed in the bleaching process to produce chlorine and caustic soda.[13]

Two interesting applications of electricity have recently been made. These are :—

(*a*) *Electric wire guides.*

One of the minor difficulties at the "wet" end of the paper machine arises from the tendency of the couch wire-mesh belt to run to one side of the rolls. On the very great widths now common in newsprint machines, a very slight error in alignment, or slight inequality in stretching of the wire, is enough to cause this trouble. A method of controlling the movement of the wire electrically has been described by Armstrong.[13] This utilises mercury switches controlling a motor which alters the position of the wire guide roll.

(*b*) *Break recording.*

The consequences of a break in the paper are made worse by the high speed of modern machines, as the paper piles up at the break at a speed of perhaps 1,200–1,500ft. per min. This accumulation of paper has to be prevented from causing a jam, and finally cleared out before production can be resumed. Any device which will reduce the chance of this accumulation therefore definitely speeds up production.

The Linggood Bowater patent covers the use of photoelectric cells to keep watch on the continuity of the paper through the machine, in conjunction with a motor-actuated jet arranged to cut down the width of the sheet at the wet end. When a break occurs in any part of the machine this jet is automatically traversed across the wire, reducing the width of paper entering the presses to about 1ft.; at the same time audible and visual warning is given to the attendants. When the trouble is rectified, this narrow band is fed right through the machine and then widened out to the full width. By this means the delay and waste resulting from a break are greatly reduced.

Photo-electric cells are also used to register the presence of water-marks at the sheet-cutters.

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Pretoria Trolley Buses.

A DESCRIPTION OF THE INSTALLATION IN THE CAPITAL OF THE UNION OF SOUTH AFRICA

By R. M. STEPHENSON, B.Sc., A.C.G.I., A.M.I.E.E.

Chief Engineer of The British General Electric Co., Ltd., of South Africa.

Fig. 1.—Double-decker trolley bus in Station Square, with President Kruger's Statue in the background.

Fig. 2.—Single-decker trolley bus.

GENERAL.

THE first trolley buses to run in the City of Pretoria, capital of the Union of South Africa, went into service on the afternoon of Sunday, August 20th, 1939. The Council's decision to supersede tramcars by trolley buses marked the latest stage in the evolution of the city's passenger transport which began before the Boer War with a system of horse trams. In 1909 the trams were withdrawn in favour of horse buses which continued to operate for a year, during which period electric tramways were in course of being installed, and at this time the transport services were taken over by the City Council.

The present service operates on the more thickly populated routes from the city to the outlying suburbs, and the vehicles employed comprise 24 single- and 10 double-decker buses which maintain an average schedule speed of 15 m.p.h. and attain a maximum of 40 m.p.h. on the level. The system covers 15 route miles, *i.e.*, 30 track miles, and further extensions are contemplated for which additional buses have been ordered but have been delayed owing to the war.

The electrical equipment of the buses is of G.E.C. design and manufacture, the chassis are by Leyland Motors, Ltd., while the bodies were built by Metropolitan-Cammell-Weymann Motor Bodies, Ltd. at their Birm-

ingham Works, and are of their patented all-metal construction.

INSTALLATION.

The inauguration of the new service entailed the usual routine of re-erection of the equipment, dismantled for shipment, conditioning of batteries, road tests on completed vehicles and suitable arrangements for maintenance. Early provision was made for the instruction of the maintenance staff on trolley bus equipment, for the institution of regular shed examination, and for the training of drivers.

In addition, it may be of interest to mention briefly one or two problems which arose directly as a result of local conditions. For instance, the new and extensive depot which had been designed for the accommodation of all the city's buses together with the municipal workshops had not been quite completed, so that the trolley buses had temporarily to be parked at night in one of the streets, and this arrangement was responsible for several unforeseen troubles such as the maintenance of tyre pressures, which is normally attended to in the sheds, and the danger of over-tensioning the trolley springs if the booms were secured under their retaining hooks, as Pretoria is liable to a sudden drop in temperature at sunset.

Fig. 3.—General view of single- and double-decker trolley buses in the Municipal Depot.

The question of tyre pressures was satisfactorily dealt with by fitting a ferrule to the drain cock on the air reservoir of each bus and using the vehicle's own air supply to inflate the tyres, while any possibility of overstraining the trolley springs was avoided by leaving the booms elevated and crossed.

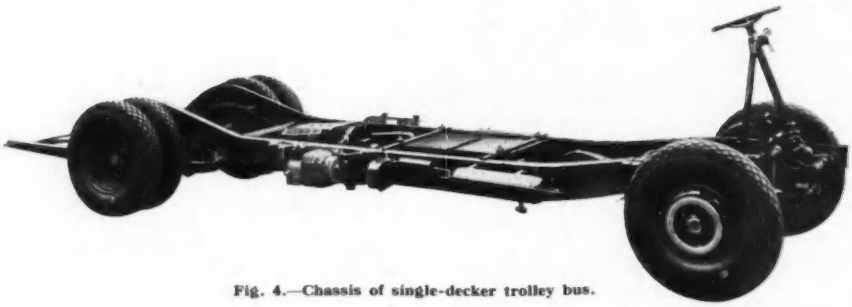

Fig. 4.—Chassis of single-decker trolley bus.

The collapse of a bridge as the result of a winter storm of unprecedented violence delayed the opening of the first trolley bus

route. Nevertheless, the last tramcar to run in the city left the terminus for the depot on the afternoon of Saturday, August 19th. Its departure was hailed by enthusiastic Pretorians as something in the nature of a civic occasion. The tramcar itself had been duly equipped with sirens and loudspeakers and decorated with flags and bunting, while from the trolley pole a Union flag fluttered at half-mast. The following afternoon the first trolley buses went into service well ahead of the time that had been allowed. The drivers quickly acquired the technique of piloting the buses, the only trouble being occasional dewirements which were mainly attributable to the enthusiasm of the drivers and their relative inexperience of the limitations imposed by heavy overhead fittings. These and other minor difficulties

Fig. 5.—General view of the trolley bus motor from the commutator end.

were so soon surmounted that within a couple of days the service was running satisfactorily.

ELECTRICAL EQUIPMENT.

General Considerations.

In the early stages of their development, trolley buses were invariably driven by series motors, and although a great many of these equipments are still in service, experience has shown that the electric motor is so free running in comparison with the internal combustion engine that brake wear tends to become excessive. As a result of this, various forms of rheostatic braking have been introduced, but the characteristic of the series motor, when acting as a generator, is not very suitable for this duty, as its back tractive effort is not naturally limited in any way and is therefore liable to impose an undue mechanical strain on the transmission. Consequently, while there exists a limited number of series motor equipments employing rheostatic braking, it cannot be said that they are in every way satisfactory, and but little progress has taken place in this direction.

However, appreciation of the benefits to be gained by using some form of electric braking led to the introduction of a regenerative system using a compound motor. This was followed almost at once by the addition of rheostatic braking which can easily be applied to this type of motor.

Subsequently, experience showed that while regenerative braking was attended by certain difficulties due to the building up of high voltage on a non-receptive line, rheostatic braking on the other hand, offered many important advantages when used with a compound motor by reason of the fact that, when acting as a generator such a machine is counter-compounded and this provides very simply an almost ideal torque characteristic, the essential feature of which is that it is inherently limited and thus fully protects the transmission from mechanical shock. The tendency has, therefore, been to use a compound motor for the sake of the easily controlled rheostatic braking obtainable, and to eliminate, either wholly or in part, the regenerative features where conditions are not favourable to regeneration. This characteristic is obtained by suitably proportioning the two fields and appropriately arranging the control gear.

The equipment supplied for the Pretoria trolley buses is of this nature; while the motor is incapable of any appreciable regeneration even at abnormally high road speeds, an excellent rheostatic braking characteristic is obtained by boosting the separately excited shunt field during braking.

Main Circuits.

Current is collected from the two trolley wires and passes through the positive and negative line circuit breakers which provide protection against overload and faults. These breakers are hand operated and are situated in the driver's cab so that they can conveniently be used for switching off the power in an emergency. In addition, there are two main contactors, one in each pole, which are operated from the power controller; being in series they ensure the opening of the main circuit even if one contactor should fail.

The main reverser for controlling the direction of travel of the bus is embodied in the master controller.

The starting resistances, which are housed under the chassis, are arranged to operate on a partial series-parallel system.

The shunt field is connected to the live side of the main line contactors so that it can be

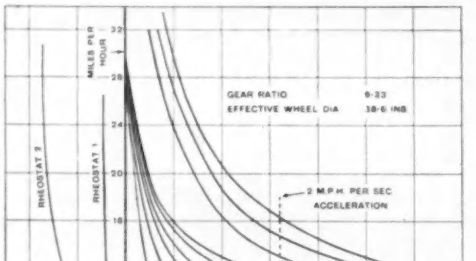

Fig. 6.—Characteristic curve of the compound motor.

excited for rheostatic braking when these contactors are open. A discharge resistance is permanently connected in parallel with this field and a controlling resistance operated by two contactors is also provided.

Operation.

(a) Motoring.

To understand clearly the action of the controller it will be helpful to follow the series of operations which take place when the trolley bus is started (see figs. 6 and 7). The double pole main auxiliary switch is first closed, thereby energising the control circuits and the compressor motor; it is impossible for the driver to run without the air compressor in operation. As soon as he has satisfied himself that air is available the driver closes the main line circuit breakers by hand.

The power controller is pedal operated and is situated under the driver's seat. On the first step the positive and negative main line contactors close thus completing the armature and series field circuits; on the second step the shunt field is excited at its normal strength for motoring. Thereafter the motor is accelerated by cutting out successively various sections of the starting resistance. Further acceleration is obtained by eliminating the shunt field and finally by diversion of the series field which takes place in two stages.

The reverser is operated by a separate hand lever and has three positions: "forward," "off" and "reverse." It is mechanically interlocked with the power and accelerating drum so that with the reverser in the "off" position the accelerating drum is also locked in the "off" position; further, the reverser cannot be moved from one position to another if the accelerating drum is in any position other than "off."

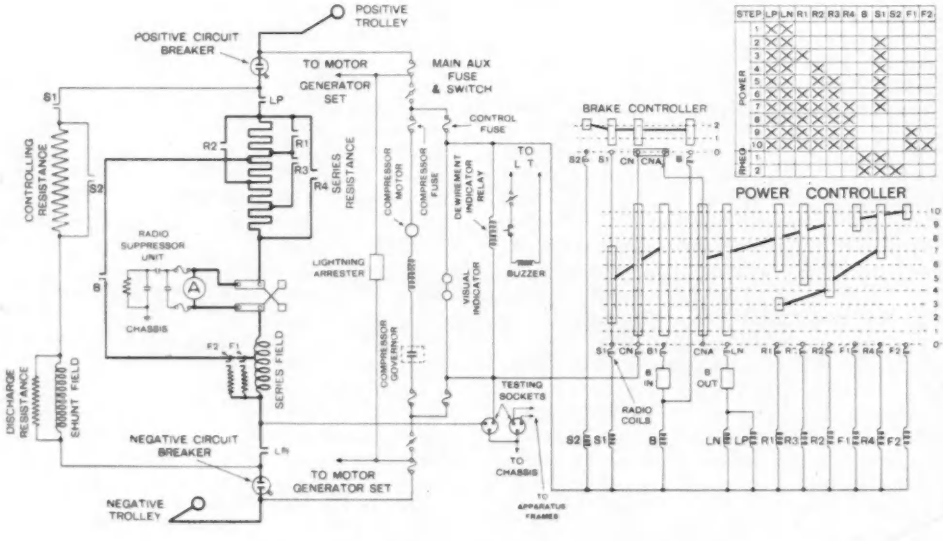

Fig. 7.—Schematic diagram of the main and auxiliary circuits.

(b) Braking.

The principal braking system is pneumatically operated, being supplied from a reservoir fed by the compressor which is automatically controlled by a pressure switch. The rheostatic braking is, of course, entirely separate and acts through the transmission, serving only to retard the vehicle which is finally brought to rest by the air brakes. The use of rheostatic braking as an adjunct to the pneumatic system materially reduces the wear on the brake drums and linings.

The power and brake controllers are built into a common frame and are connected to their respective pedals by links under the cab floor. When the brake pedal is depressed the line contactors open and the motor is connected across part of the starting resistance which dissipates the electrical energy generated. At this stage normal shunt field excitation is used together with a definite amount of series field. On the second step the shunt field resistance is cut out thereby raising the excitation to a maximum and correspondingly increasing the braking effort. As already explained, during motoring the shunt and series fields assist each other but during braking they oppose each other. The effect of this opposition is automatically to limit the braking torque of the motor, thereby safeguarding the propeller shaft and the transmission generally from excessive strain. As soon as the vehicle has been adequately retarded the pneumatic braking is put into operation and brings it to rest.

The motoring and brake controllers are electrically interlocked so that as soon as rheostatic braking is begun the motoring contactors open and cannot be put into operation again until both controllers have been returned to their "off" positions. The absence of such an interlocking arrangement would mean that if braking were employed with the motoring controller on, as might be the case in an emergency, the return of the brake controller to the "off" position would suddenly re-introduce motoring at a point in the running cycle corresponding to the step on which the controller had been left. This is obviously not permissible and is prevented by the provision of the interlock.

Auxiliaries.

The auxiliary circuit is provided with fuses in both positive and negative sides thus affording two lines of protection for all auxiliaries and obviating any trouble which might arise from a single faulty fuse.

The motor driving the air compressor is connected in parallel with the control circuit and is energised by the closing of the main auxiliary switch thus ensuring that it shall always be in operation when the bus is in service.

A motor-generator set carried on the chassis and driven from the 500 volt line supplies the usual low voltage lighting system in association with a floating battery. This generator is similar to that used on the ordinary petrol bus except that it is driven by a separate motor instead of from the engine.

Accessories.

In order to attract the attention of the driver should a trolley pole leave the overhead wire, visual and audible dewirement indicators are fitted in the cab. Both indicators are

Fig. 8.—View of the driver's cab showing the controller situated under the driver's seat and the contactor panel on the extreme right, with covers removed in each case. One of the breakers can be seen in the roof.

connected across the supply voltage, the visual signal consisting of two 250 volt lamps in series, while the audible type embodies a relay which closes a low tension buzzer circuit.

Means are provided for testing the insulation of all electrical circuits. For this purpose the necessary testing sockets, housed

in a suitable case, are mounted in the driver's cab and so arranged that two methods of testing can be employed. Normally, all the conductors are made alive at 500 volts and the total leakage across all forms of insulation is determined by the use of a milliammeter; but in the event of a bad

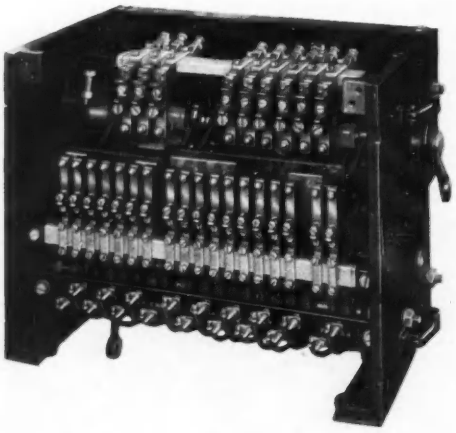

Fig. 9.—Detail view of a typical controller with covers removed.

leakage being recorded each piece of apparatus can be separately megger tested between its frame and the chassis.

To prevent interference with radio reception in the localities in which the buses operate, a wireless suppresser is fitted to the main motor and suitable choke coils are connected in circuit with the fingers of the master controller.

In view of the prevalence of thunderstorms in the Transvaal the trolley buses are provided with suitable lightning arresters as a protection against over-voltage in the event of a lightning stroke.

OPERATION OF SERVICE.

The central terminus of the service is Church Square where the principal Government Buildings are situated. The Square is the focal point from which the main streets radiate. All routes run into and around the Square and the overhead wiring has been doubled and arranged with numerous cross-overs to allow stationary buses to be passed by those entering or leaving the terminus.

The efficiency of the trolley bus service has been greatly appreciated by the citizens of Pretoria who have been impressed both by the speed and silence of the vehicles as well as by the frequent and regular schedule which has been maintained. As a result the passengers on these routes have increased by some 20 per cent and now number about 7,000,000 a year. In addition to the trolley buses there are in operation thirty-one compression ignition and twenty-four petrol buses which carry a further 9,000,000 passengers a year.

Pretoria being the Administrative Capital of the Union, a large proportion of the citizens are civil servants employed in the government buildings in the neighbourhood of Church Square, which gives rise to a peak demand on transport around 8.30 in the morning and 4.30 in the afternoon. Between 5.30 and 7.30 in the evening little demand is made on the service, but from the latter hour a further demand for transport arises due to people coming into town again to attend various places of amusement. This demand continues fairly steadily until the last bus leaves at 11.30 p.m.

THE CITY AND ITS LOCALITY.

Pretoria, together with its town lands, covers an area of almost 60 square miles on either side of the Aapies River, which is spanned by seven bridges. The city, standing 4,500 feet above sea level, lies in a valley between ranges of hills running east and west, and is laid out on the American plan in rect-

Fig. 10.—Typical contactor panel with covers removed.

angular blocks. Most of the streets are planted with avenues of trees, the most famous of which is the jacaranda, which flowers in November, and during this month one week

is observed as "Jacaranda Week" when, in peace time, the Square is hung with decorations and illuminated and open-air shows take place in the evening.

Church Square is laid out on an imposing scale with lawns and flower gardens in the centre and the various public buildings flanking the sides. It has been said that this square will bear comparison with any in the Southern Hemisphere.

The Union Government Buildings are situated on Meintjes Kop, about 2 miles from the centre of the town, and overlook the city and its suburbs. They were erected in 1910–13 to the designs of Sir Herbert Baker and are considered a remarkable architectural achievement. The site they occupy was described by Lord Selborne as one of the finest in the world.

Two official languages are recognised in the Union and all official notices, street names, most advertisements, as well as destination indicators on public vehicles and bus tickets are printed both in English and Afrikaans.

There is little or no rain in the Transvaal during the winter, but from October until the end of April violent thunderstorms are liable to occur, which last continuously for hours and are accompanied by heavy rain. The prevalence of these storms makes it imperative to provide the trolley buses with lightning arresters as a protection against possible damage from this cause.

Traffic laws vary in different parts of the Union. In Pretoria, for instance, trolley buses are not required to be registered and consequently carry no registration number. Most of the principal towns of the Union, including Pretoria, have their own traffic police, a number of whom are mounted on fast motor cycles. These police constitute a separate body from the ordinary civil police force.

About a quarter of the population are natives who live in separate townships inside the city boundaries under the supervision of the municipality. These communities have their own dance halls, tennis courts and football teams, and still practise the divers ceremonial war dances, which, however, are now usually organised on a competitive basis between teams selected from the various compounds.

Paul Kruger's house still stands in Church Street West, a short distance from Church Square, and is now used as a Museum. The ex-president's birthday is celebrated each year, the day being one of Pretoria's recognised holidays.

FUTURE DEVELOPMENTS.

The success of the original five sections turned over to trolley bus operation promptly led to the decision to extend the service to other routes, in particular to the Capital Park and Riviera routes and that linking the existing Sunnyside and Brooklyn routes. Unfortunately, the outbreak of war within a few days of the inauguration of the first sections has unavoidably delayed these projects, but there seems no doubt that as soon as conditions return to normal a greatly increased service of trolley buses will be adopted for use in the city and suburbs.

ACKNOWLEDGMENTS.

Both in respect of the installation of the service and in the preparation of this article the author desires to acknowledge the helpful co-operation of the following officials of the Pretoria City Council: Mr. D. J. Hugo, City Electrical Engineer; Mr. W. T. Christie, Manager of the Transport Department; Mr. E. McElroy, Mechanical and Transport Engineer, and Mr. F. Grant, Depot Superintendent, who is at present on active service with the South African Forces. It should, perhaps, be added that the first trolley bus to go into regular service was piloted from Church Square by Councillor F. Hopf, Chairman of the Trading Committee, who has always been a strong advocate of trolley buses.

The Consulting Engineers were Messrs. Merz & McLellan who supervised the execution of the contract, which included running tests on the buses prior to their shipment to South Africa. These tests were performed under the supervision of Mr. Inglis representing the Consultants.

Quality Control.

STATISTICS AS AN AID TO PRODUCTION EFFICIENCY.

By B. P. DUDDING, M.B.E., Ph.D., and W. J. JENNETT, B.Sc. (Eng.), A.M.I.E.E.

G.E.C. Research Laboratories.

This article calls attention to the emphasis which war production has placed on the use of statistical methods as an aid to efficient production, and to the authors' recent revision of the Control Chart portion of British Standard 600—1935. *The revision, in hand-book form, gives all the instructions and information necessary to the introduction of the methods to factory procedure.*

Reference is made to earlier articles appearing in the G.E.C. Journal.

Armament production has emphasised very strongly the need for raising the efficiency of utilisation of labour and material. With this in view a meeting of engineers held in London on April 15th, under the auspices of the Institutions of Civil, Mechanical and Electrical Engineers, brought prominently to notice a factory procedure which for brevity is referred to as "Quality Control." The procedure is one by which methods of plotting test data, based on statistical principles, are used to give guidance to those responsible for manufacturing products which have to comply with quality specifications. For some years a few firms in the United States of America and in England have been using the methods, and the publication of two articles in the G.E.C. Journal* is evidence that the G.E.C. has been numbered among them. At the joint meeting referred to above, Mr. George Chelioti, Manager of the Osram-G.E.C. group of factories, pointed out that the more usual methods of inspection are in the nature of sorting processes whereas the aim of "Quality Control" is so to use the results obtained from sampling inspection at stages in the production line that unsatisfactory product is largely eliminated. Further, he stated that even where "Quality Control" had been introduced, much more general application was possible before it could be said to be consistently applied. At the same meeting Sir Frank Gill summarised the distinguishing features of "Quality Control" as follows :—

"(1) Regular measurement or gauging of relatively small samples according to a predetermined plan.

(2) Instant charting of the results of the above operations.

(3) Control limits fixed by statistical method and quite independent of the engineering or specification limits.

(4) Constant exhibition of the charts where the production force can easily fulfil its duty of knowing and understanding the information on them and, in co-operation with the inspection force, of taking prompt action."

Before the meeting was arranged the authors of the present article had been asked by the British Standards Institution to undertake the revision of the portions of British Standard 600* published in 1935, which dealt specifically with the construction of "Control Charts," which are the core of "Quality Control."

"Control Chart" was the name given by Dr. W. A. Shewhart in 1926 to a diagrammatic presentation of test results against a background of statistically derived limits. The limits used by him were based mainly on the theoretical work of British statisticians. British practice as portrayed in British Standard 600—1935 and in British Standard 600R—1942 uses refinements based on later work by British statisticians.

British Standard 600R—1942 gives, in concise form, the instructions and tables necessary to engineers introducing "Quality Control" into factory practice.

It may be of assistance to recall briefly the ideas underlying "Quality Control." The

*(1) B. P. DUDDING and W. J. JENNETT. "Statistical Technique as a Tool in Industry" (*G.E.C. Journal*, Vol. VII, No. 3, Aug. 1937).

(2) B. P. DUDDING and W. J. JENNETT. "Statistics and Engineering Practice" (*G.E.C. Journal*, Vol. XI, No. 3, Feb. 1941).

* British Standard, 600—1935. E. S. PEARSON. "The Application of Statistical Methods to Industrial Standardisation and Quality Control."

First part of revision as: British Standard 600R—1942. B. P. DUDDING and W. J. JENNETT. "Quality Control Charts." Obtainable from the British Standards Institution, 28, Victoria Street, London, S.W.1. Post free, 3/10.

primary objective is to demonstrate whether or not the production processes are stable. What is meant by stability of manufacturing procedures can be illustrated by means of an apparatus first designed by Galton about 50 years ago. The apparatus is shown in fig. 1. In it some balls are fed through a funnel set vertically over an array of receptacles of equal size. In the absence of any disturbing factors balls fed singly would fall into the middle receptacle. To act as centres of disturbance pins are placed at equal distances in rows and between rows.

The effect on the balls is to disturb them so that they do not fall wholly in the middle receptacle, but are distributed among the receptacles, as in fig. 1.

The actual distribution simulates closely that known as the "Gaussian" or "Normal" distribution. If the balls be returned to the hopper and the experiment repeated several times the distribution remains sensibly constant both in position and diversity. It is this repetition of the position and form of the distribution that warrants the use of the terms "control" or "stable" in describing it, although there is appreciable spread in the position of individual balls.

Similarly, in production, in spite of considerable divergence in the properties of individual articles the production is "controlled" or "stable" provided the quality of the product remains essentially the same both in respect to its average value and the variation in the individual values as exhibited by the distribution curve. That is, if all the product from a machine or process made during convenient periods, say per hour, day, or shift, be measured and the results presented as a distribution similar to fig. 1, then the production would be said to be stable if the distributions remained closely the same. A similar criterion would apply at any one time if different machines were used to produce the same product.

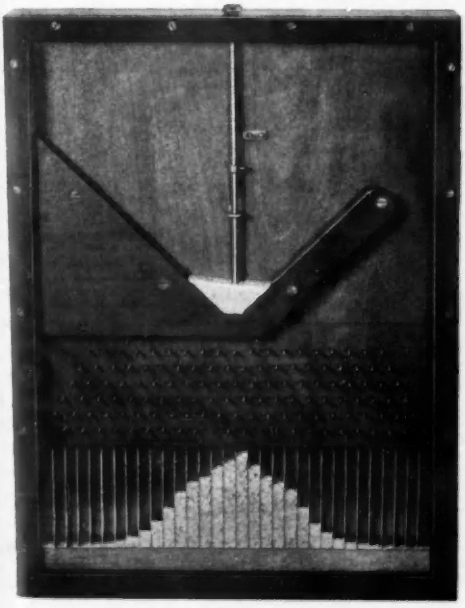

Fig. 1. Galton apparatus.

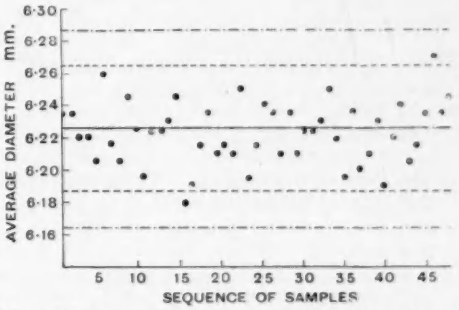

Fig. 2. Typical control chart for a product "in control." Gauging of glass tubing; averages of samples of 8 pieces.

The control chart (illustrated in fig. 2) utilises the results for samples chosen from the sub-group of the product, such as that made on a machine in one hour. The position of plotted results in relation to limits derived by reference to the appropriate section of British Standard 600R—1942, demonstrates whether or not the production processes are in control.

Should instability be indicated by the occurrence of points outside the control chart limits, then the engineers in charge of production have guidance as to the origin of variability, that is, the source of a disturbing variation can be assigned.

"Quality Control" will lead gradually to the elimination of these variations due to assignable causes leaving only the variations due to chance, that is, those which must be expected from the standard production processes.

The methods are not difficult to apply and the authors have generally found that when assisting factory personnel to introduce the methods the data necessary are already available in some form as a result of the normal factory inspection.

Technical Literature.

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES.

THE PERFORMANCE OF COMMUTATOR INVERTERS.*

By L. C. Stenning, (Research Laboratories).
Wireless Engineer, Vol. 17, p. 517, Dec., 1940.

This paper deals with the circuit design of commutators and inverters of the vibrator gas discharge rotary commutator type and the calculation of the performance of these circuits on the assumption that their transformers do not distort the square wave form of the input alternating voltage and current.

ANODE DISSIPATION IN ANODE-MODULATED CLASS C AMPLIFIERS.*

By R. G. Mitchell (The M.O. Valve Company and G.E.C. Research Laboratories).
Wireless Engineer, Vol. 18, p. 443, November, 1941.

The effect on anode dissipation of anode modulation is investigated theoretically and also by practical tests. Formulae are developed to facilitate the assessment of the anode dissipation for any depth of modulation. The effect of non-linearity of the amplifier is discussed. An analysis is given showing how the input is distributed between the H.T. and modulator source.

THE DISTRIBUTION OF AUTELECTRONIC EMISSION FROM SINGLE CRYSTAL METAL POINTS. II. THE ADSORPTION MIGRATION AND EVAPORATION OF THORIUM, BARIUM AND SODIUM ON TUNGSTEN AND MOLYBDENUM.*

By M. Benjamin and R. O. Jenkins (Research Laboratories).
Proc. Roy. Soc., Vol. 180, p. 225, June, 1942.

The adsorption, migration and evaporation of thorium, barium and sodium on tungsten and molybdenum have been studied by means of autelectronic patterns from single crystal points of these metals. It is found that migration occurs at relatively low temperature and that there is a unique distribution of the migration atoms on the metal crystal which varies as the temperature.

THE TRANSMISSION CHARACTERISTICS OF ASYMMETRIC SIDEBAND COMMUNICATION NETWORKS.*

By E. C. Cherry (Research Laboratories).
J.I.E.E. Vol. 89, Part III., March, 1942.

An investigation is made into the theoretical and practical aspects of the partial suppression of one or both side bands of a modulated carrier wave. The work is primarily of importance in connection with asymmetric channels, in particular, television broadcasting channels.

THE REPLACEMENT OF PERISHABLE MEMBERS OF A CONTINUALLY OPERATING SYSTEM.*

By N. R. Campbell (Research Laboratories).
Supplement to the J. Roy. Statistical Soc., Vol. 7, p. 110, 1942.

The question discussed is whether, in a series of street lighting posts which have to be kept supplied with lamps, it is cheaper to replace the lamps individually as they fail, or to replace all the lamps at regular intervals, replacing individually only those that fail between the intervals.

FLUORESCENT LIGHTING.*

By H. G. Jenkins (Research Laboratories).
J. Roy. Soc. of Arts, Vol. 90, p. 282, April 3rd, 1942.

The development of tubular fluorescent lamps is described with particular reference to the 5 ft. 80 watt tube.

THE SHOT EFFECT IN A SATURATED DIODE*

By N. R. Campbell and V. J. Francis (The M.O. Valve Co. and G.E.C. Research Laboratories).
Phil. Mag., Vol. 32, p. 496, December, 1941.

In the continuation of a previous paper it is again proved that both Campbell's and Shottky's theorems lead to the same result when applied to calculate the shot noise in the external circuit of a saturated diode. In this paper, contrary to the former, it is not assumed that the circuit impedances are all lumped or that the transit time of the electrons is infinitely small.

*** A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, Birmingham, 6.**

LOW OIL-CONTENT METALCLAD SWITCHGEAR.
By C. J. O. Garrard (Witton Engineering Works).
Engineering, Vol. 153, p. 514, June 26th, 1942.

A description of the construction of a new type of metalclad switchgear and of the methods employed to limit the amount of oil contained in the circuit breakers and busbar enclosures, together with a discussion of the ideas which led to the new development.

TESTING HIGH VOLTAGE CIRCUIT BREAKERS.
By C. J. O. Garrard (Witton Engineering Works).
Engineer, Vol. 173, pp. 511 and 530, June 19th and 20th, 1942.

From the known trends of the growth of electricity supply systems it is shown that circuit breakers for higher voltages and breaking capacities than those at present available will be needed within a few years. Existing testing plants are probably inadequate for testing such breakers. Some proposed synthetic testing circuits are discussed and their value found to be doubtful. Other expedients such as composite testing and separate testing of the individual breaks of multi-break breakers are more promising, while the more extended use of field tests is recommended.

ELECTRICITY IN PAPER MILLS.
By W. J. Mason (Engineering Dept.) and S. A. G. Emms (Witton Engineering Works).
Jour. I.E.E., Vol. 88, No. 5, Pt. II., p. 467, October, 1941.

The second part of this paper is reprinted on p. 92 of this issue of the *G.E.C. Journal*. Part I appeared in Vol. XII., No. I., February, 1942, of the *G.E.C. Journal*.

THE CATHODE RAY OSCILLOGRAPH IN INDUSTRY.
By W. Wilson (Development Laboratory, Witton).
Chapman & Hall.

This book has been written primarily for the user. Historical matter and mathematical theory are omitted enabling fuller attention to be given to the make-up of the present-day tube. The conduct of tests with the various kinds of cathode ray oscillograph is described and includes such diverse subjects as lightning strokes, aero engine indication, musical quality, echo ranging, hysteresis in iron, short circuits on circuit breakers, and bomb explosions. The scheme adopted throughout consists of an analysis of each problem, leading to a description of the method of test, followed by examples of the resultant oscillograms derived from industrial practice.

THE CALCULATION AND DESIGN OF ELECTRICAL APPARATUS. (Third Edition).
By W. Wilson (Development Laboratory, Witton).
Chapman & Hall.

In this edition special attention is paid to economy in the use of copper; the calculation of convection and radiation cooling has been given more practical treatment, assisted by tables of emissivities of various surfaces, and formulæ for short-time ratings. Heavy conductor design is treated more rationally, with two new diagrams for estimating skin and proximity effects and new tables of carrying capacities. A calculation has been added for estimating the asymmetry factor during switching operations and the duration of the D.C. component.

ELECTRICAL MUSIC.
By W. Wilson (Development Laboratory, Witton).
Jour. I.I.E., p. 142, March, 1941.

The characteristic tones of ordinary instruments are analysed, and methods of generating and combining harmonics to give any desired tone colour are described. An account is given of the principal electrical musical instruments in existence today and of the advantages of the new synthetic instruments, particularly the electronic organ. The paper concludes with a short forecast as to the future of this type of music making.

APPLICATIONS OF THE CATHODE RAY IN INDUSTRY.
By W. Wilson.
B.E.A.M.A. J., January to August, 1942.

This series of articles has been appearing monthly since January, 1942, and is written primarily in the interests of the user. The method adopted is to describe the performance of the various tests with the aid of connection diagrams, and to illustrate this with typical oscillograms derived from actual practice.

DOUBLING EFFECT.
By W. Wilson and H. C. Fox.
Electrical Engineer and Merchandiser (Australia), Feb., 1942.

An analysis of the cause of current doubling through asymmetry is given with a method of calculating the asymmetry factor and duration under various conditions. A table of representative values is deduced.

THE RUNNING AND MAINTENANCE OF MARINE DIRECT CURRENT ELECTRICAL MACHINERY.

By C. Wallace Saunders (Marine Department).

Trans. Inst. of Marine Engineers, Vol. 54, No. 6, p. 69, July, 1942.

This paper summarises for the benefit of prospective and serving engineers the most satisfactory methods of running and maintaining electrical plant on board ship. In addition to general maintenance instructions, the importance of preserving drawings, diagrams and spares charts is particularly emphasised.

ELECTRICAL BALANCING MACHINES.

By S. F. Philpott (Witton Engineering Works).

Electrical Review, Vol. 131, p. 37, July 10th, 1942.

One of the most important processes in the manufacture of machinery running at relatively high speeds is the elimination of unbalance in the rotating parts. In this article the principles of dynamic balancing are discussed and there follows a description of several types of balancing machine in which the position and extent of the out-of-balance forces can be quickly and accurately determined by electrical means.

RESISTANCE FURNACES.

By Verdon O. Cutts.

Electrical Review, Vol. 130, pp. 555-7, May 1st, 1942.

The resistance furnace and the high frequency induction furnace are both considered, and various types of the former are described in some detail with particulars of the considerable number of purposes for which they are being used at the present time. The economy and consistency of operation as well as the precise control obtainable with the resistance furnace account for its increasing use in processes connected with war production.

ELECTRODE-TYPE SALT-BATH TOOL-HARDENING FURNACES.

By Verdon O. Cutts.

Engineering, Vol. 154, p. 27, July 10th, 1942.

The construction and operation of the electrode-type salt-bath furnace are described with the aid of diagrams and photographs, and details are given of its use in the heat treatment of high speed tool steels and the brazing of tungsten carbide and other tips on to medium carbon steel shanks or bodies.

INTRODUCTION TO VALVES, INCLUDING REFERENCE TO CATHODE RAY TUBES.

By F. E. Henderson (Osram Valve Dept.)

Published by the Wireless World, for The General Electric Co., Ltd.

This manual has been specially prepared for those who, with little or no previous experience, are called upon to handle radio valves and cathode ray tubes and their associated devices. The information is presented in a form easily understood and should prove particularly helpful at the present time.

THE RADIO AND TELECOMMUNICATIONS DESIGN MANUAL.

By R. E. Blakey.

Sir Isaac Pitman & Sons (2nd Impression), 1942.

This manual deals with the basic principles of design of radio components and test apparatus and covers a wide field of measurements on component parts commonly used in the radio and telecommunications industries.

Numerous commercial examples of test equipment are dealt with at some considerable length, and many tables greatly facilitating design are included.

WAVE GUIDES.

By H. R L. Lamont (Research Laboratories).

Methuen (Monographs on Physical Subjects). 4/-.

It has long been known that the interior of a single hollow tube acts as a guide for electromagnetic waves of suitably short wavelength—of the order of the diameter of the tube. With the continually extending range of valve oscillators, the use of these wave guides in radio communication systems has become feasible, and recently much work, theoretical and practical, has been published.

In this book, after an introductory chapter, the general theory of wave propagation in such guides is developed. From this are deduced the transmission line properties of particular shapes of tube, and attenuation formulæ for the various wave types are derived and compared with those of the more familiar transmission lines. There follow chapters on wave guides as high-Q cavity resonators, and on the radiation patterns produced by open-ended and flared tubes used as radiators.